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ANALYSIS OF ARMY FIXED-WING CARGO RESTRAINT DESIGN CRITERIA

By

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U. S. ARMY AVIATION MATERIEL LABORATORIES
FORT EUSTIS, VIRGINIA

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DEPARTMENT OF THE ARMY
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A requirement to determine analytically the acceleration-time relationships for the cargo compartments of CV-2 and CV-7 aircraft, when subjected to various crash conditions, and to determine the effect of these relationships on a load-limited restraint system provides the basis for this report. The techniques used in this report represent a logical extension of previous, similar programs; in the absence of test-crash data, the results contained herein may be used with a high degree of confidence.

The excessive load-limiter displacements (2 to 16 feet) indicated for certain crash conditions considered in this report are judged to be operationally unacceptable by this activity. However, the load-limiter concept represents a significant safety and operational improvement over the conventional restraint devices for most of the crash conditions considered. This activity suggests that a trade-off study be conducted to determine the maximum safety that can be achieved by load-limited restraints commensurate with acceptable operational factors.

Since the Army no longer has operational responsibility for the CV-2 and the CV-7 aircraft, this activity has not planned further effort in the area of this report. However, results of this contract will be forwarded to the appropriate Air Force agency for consideration.

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ANALYSIS OF ARMY FIXED-WING CARGO RESTRAINT DESIGN CRITERIA

Final Report
AvSER 66-21

By

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SUMMARY

This report presents the findings of an investigation into the crash pulse of fixed-wing cargo aircraft and the resulting behavior of cargo restrained by load limiters.

A crash pulse simulator computer program was developed that obtains acceleration-time histories at selected stations in the cargo compartment and under various crash conditions. This simulator was employed to obtain crash pulses for a wide range of input parameters, both for the CV-2 and the CV-7 Army aircraft. The resulting acceleration pulses were studied to determine a suitable spectrum of realistic pulses.

The crash pulse program was subsequently modified to include a routine that would simulate cargo dynamic behavior during the crash sequence, employing the floor acceleration data as it is developed. This latter program was applied to CV-2 and CV-7 aircraft, under significant crash conditions, to obtain the dynamic response of cargo to the crash pulse.

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CONTENTS

SYMBOLS

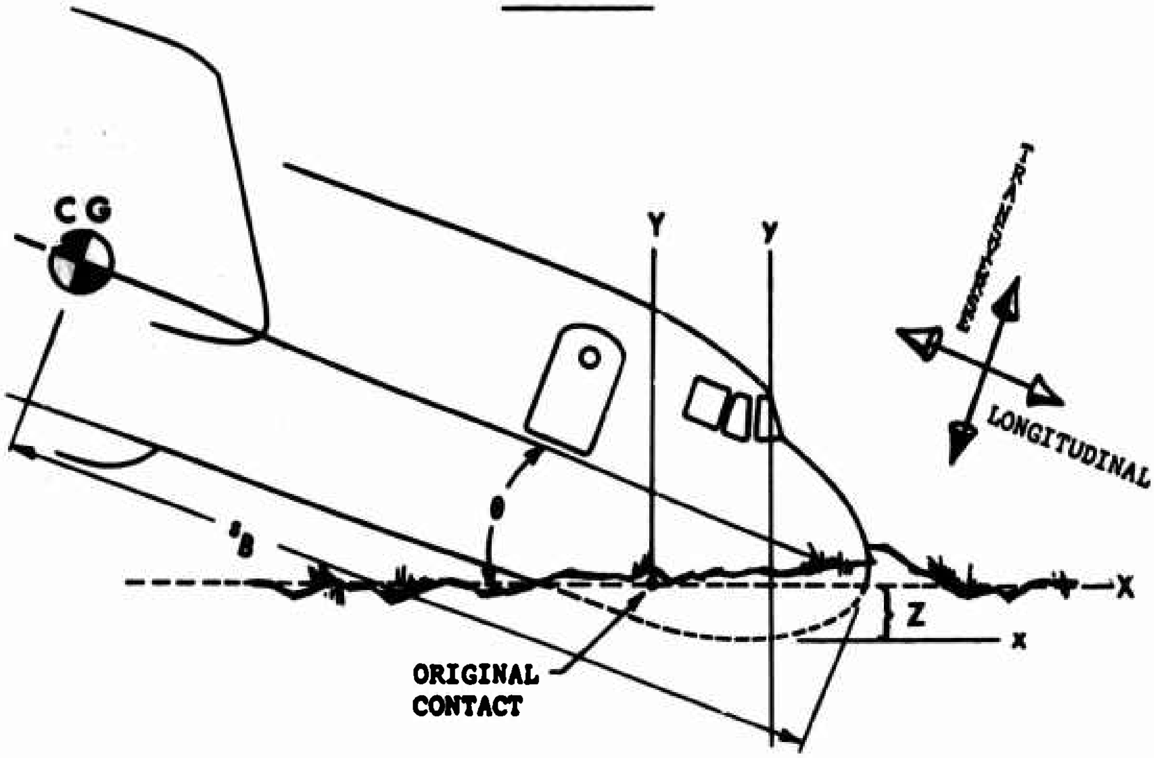


Figure 1. Sketch Illustrating Symbols.

a_C	Longitudinal acceleration of cargo (ft/sec^2)
a_{FL}, a_{FN}	Longitudinal and normal accelerations respectively of cargo compartment floor (ft/sec^2)
$\bar{a}_i$, a_i	Rigid body acceleration components (transverse and longitudinal) at i^{th} station (ft/sec^2)
a_{REL}	Relative cargo acceleration (ft/sec^2)
a_{Ti}	Total longitudinal acceleration at i^{th} station (ft/sec^2)
a_{Vi}	Contribution to acceleration due to transverse vibration at i^{th} station (ft/sec^2)
A_{jk}	Coefficients in polynominal expressions for functions of the angle θ

B	Symbol for algebraic expression
C	Longitudinal component of ground reaction (lb)
$C_1 \ldots C_4$	Soil parameters
D_{XF} D_{YF} D_{XR} D_{YR}	Algebraic expressions involving coordinates of points (ft)
Den	Symbol for algebraic expression
EI	Flexural rigidity of fuselage (lb-ft^2)
f	Coefficient of friction between aircraft and ground
f_C	Coefficient of friction between cargo and cargo compartment floor
F_N F_T	Normal and tangential components of ground reaction force (lb)
F_{N1} F_{N2} F_{N3}	Components of F_N (lb)
F_{T1} F_{T2} F_{T3}	Components of F_T (lb)
F_{LL}	Forward load-limiter limit acceleration (ft/sec^2)
g	Symbol for algebraic expression
$G_1 \ldots G_{10}$	Algebraic expressions

G	Symbols for unit of acceleration equivalent to 32.2 feet per second per second
$h_n(t)$	Symbol for expression,function of time
$H_1 \ldots H_9$	Input parameters expressed as functions of the angle θ
I_A	Mass moment of inertia of aircraft (slug ft^2)
I_F, I_R	Mass moment of inertia of forward and of aft sections of aircraft
k	Reduction factor
K_1	Structural parameter
L	Length of fuselage (ft)
m_A	Mass of aircraft (slugs)
m_F, m_R	Mass of forward and of rear sections of aircraft (slugs)
$m_1 \ldots m_4$	Generalized masses (for Lagrange's equations) (slugs)
M_B	Computed fuselage bending moment (ft-lb)
M_H	Yield hinge moment (ft-lb)
P	Transverse component of soil reaction force (lb)
$q_1 \ldots q_4$	Generalized coordinates (for Lagrange's equations) (ft)
$Q_1 \ldots Q_4$	Generalized forces (for Lagrange's equations) (lb)
r	Magnitude of space vector (ft)
R_{LL}	Rear load limiter limit acceleration (ft/sec^2)
s	Distance from nose as an indepentent variable (ft)
s_i	Distance from nose to i^{th} station (ft)

s_B	Distance from nose to center of gravity (ft)
s_{BF}, s_{BR}	Distance from nose to center of gravity of forward and rear sections (ft)
s_J	Distance from nose to J^{th} station (ft)
S_C	Scoop factor
t	Time (sec)
v_{REL}	Relative cargo velocity (ft/sec)
x, y	Coordinates of aircraft center of gravity from x, y axis system (ft)
X, Y	Coordinates of aircraft center of gravity from original point of contact (ft)
X_F, Y_F; X_R, Y_R	Coordinates of centers of gravity of forward and rear sections, respectively (ft)
X_H, Y_H	Coordinates of yield hinge (ft)
Z	Interference of aircraft original contour with soil (ft)
Z_G	Actual penetration of ground by aircraft (ft)
$\dot{X}, \dot{Y}, \dot{Z}\ldots$	Time derivatives of quantities X, Y, Z...
$\ddot{X}, \ddot{Y}\ldots$	Second time derivatives of quantities X, Y...
β	Damping coefficient for longitudinal vibration
θ	Angle of impact of aircraft (rad)
θ_F, θ_R	Attitude angle for forward and rear sections of aircraft, respectively (rad)
Δt	Time increment (sec)
$\Delta ()$	Change in quantity () during time increment Δt

μ_i	Mass of i^{th} discrete segment of fuselage (slugs)
μ	Mass per unit length of fuselage (slugs/ft)
$\phi_1 \ldots \phi_4$	Normal mode shapes for free vibrations
$\omega_1 \ldots \omega_4$	Natural angular frequencies (rad/sec)
$\bar{\omega}_1 \ldots \bar{\omega}_4$	Resonant frequencies with damping (rad/sec)

SUBSCRIPTS

i	Associated with i^{th} station or fuselage segment
n	Associated with n^{th} generalized coordinate in Lagrange's equations
F	Associated with forward section of aircraft
R	Associated with rear section of aircraft
H	Associated with yield hinge
J	Associated with J^{th} station

INTRODUCTION

This report represents a continutation of the analytical investigation of acceleration-time pulses for the CV-2 and CV-7 aircraft as described in USAAVLABS Technical Report 65-30, "Cargo Restraint Systems for Crash Resistance". The crash impact parameters and limits thereof used in this program were felt to represent the conditions most likely to be encountered in an accident for the aircraft involved. In addition, it was felt that all of these conditions represented a survivable accident.

CRASH PULSE SIMULATOR

DESCRIPTION

The computer program to simulate dynamic behavior of a fixed-wing aircraft accepts as input (1) accident configuration variables, (2) structural data for the specific aircraft, and (3) soil behavior parameters. The accident configuration variables consist of velocity, sink rate, impact angle, and angular velocity (if present). The structural input data include flexural and axial stiffness properties, mass distribution data, buckling, yield and failure criteria, and various geometric data. The soil reaction parameters relate the interaction forces between aircraft and ground to the depth of penetration, the rate of penetration, and the horizontal velocity.

The simulator output is in the form of computer-plotted acceleration-time curves for three stations in the cargo compartment. Additionally, the simulator displays the maximum plowing depth, the groove length, the maximum values of generalized coordinates for vibration modes excited by crash forces, the maximum stresses in the fuselage, and the kinematic data at the completion of rebound (or slide-out).

ANALYTICAL BASIS

The simulator operates in either of two general modes: the elastic mode or the plastic-hinge mode.

The elastic mode is assumed if fuselage (longitudinal) stresses are below buckling or plastic limits. In this mode the dynamic behavior of the aircraft is divided into two parts: First, the rigid body behavior is obtained from the soil-structure interaction forces and rigid body equations of motion. Second, the vibration modes excited both by the soil reaction forces and by the rigid body motion inertial forces are evaluated.

The vibration amplitudes are found by means of a normal mode analysis in which the first and second transverse and the first and second longitudinal modes of fuselage vibration are considered. The amplitudes of these four vibrational modes are taken as generalized coordinates in Lagrange's equations of motion for the aircraft. For the assumption that the damping coefficient is proportional to mass distribution along the

fuselage (an assumption which introduces little error), the Lagrange's equations reduce to a set of independent one-degree-of-freedom equations:

$$\ddot{q}_n + \beta \dot{q}_n + \omega_n^2 q_n = \frac{Q_n}{m_n}$$

where

$q_n, \dot{q}_n, \ddot{q}_n$ = generalized coordinates and time derivatives

β = damping coefficient

ω_n = natural angular frequency

Q_n = generalized force

m_n = generalized mass

$$Q_n(t) = \int_0^L p(x,t)\,\phi_n(x)\,dx + \Sigma\, P_i(t)\,\phi_n(x_i)$$

$$m_n = \int_0^L \mu\phi_n^{\,2}\,dx$$

A solution satisfying initial conditions is found in the convolution integral:

$$q_n(x,t) = \frac{1}{m_n\bar{\omega}_n}\int_0^L Q_n(T)\exp\left[-\frac{\beta}{2}(t-T)\right]\sin\bar{\omega}_n(t-T)\,dT$$

which is evaluated numerically in the simulator program (reference Appendix I). With the generalized coordinates evaluated, the vibrational kinematics are determined and may be superimposed on the rigid body kinematics to obtain resultant accelerations. The maximum bending stresses are determined from the bending moments associated with the transverse vibrational modes of the fuselage.

The plastic-hinge mode of aircraft behavior is followed by the simulator, if at some fuselage station the effective buckling or the yield stress has been exceeded (when operating in the elastic mode). In the plastic-hinge mode, the aircraft is treated as two rigid bodies joined by a plastic "yield hinge" which may transmit hinge reactions as well as a plastic-hinge bending moment. In this mode, elastic vibrations are ignored, as they are con-

sidered to be negligible when compared with the large plastic deformations. Again, the equations of motion are solved by numerical integration.

The simulation is terminated by any of the following conditions:

1. The rebound has been completed; that is, the soil penetration has returned to zero.

2. The horizontal component of velocity has been reduced to zero.

3. The deflection angle at the plastic hinge has reached a critical value, implying a fuselage break.

4. The aircraft rotates outside a specified angular limit (implying an overturning).

A flow chart and an outline of computational operations of the simulator program are provided in Appendix I.

DEVELOPMENT OF INPUT DATA

The input data for crash simulation of the CV-2 and CV-7 Army aircraft are divided into three categories: accident configuration variables, structural data, and soil reaction parameters. An example of input data for a simulation run as developed for the CV-7 aircraft appears in Appendix IV.

ACCIDENT CONFIGURATION DATA

The accident configuration variables used were those specified in the contract statement of work.

STRUCTURAL DATA

The mass distribution data have been obtained from weight analyses made by the manufacturer. These data were adjusted in accordance with various cargo and fuel level conditions for several simulator runs.

The structural stiffness data may be conveniently separated into two groups: that which deals with the vibrational behavior of the aircraft, and that which relates imposed forces to structural deformation.

Consider, first, the vibrational behavior. The mode shapes and natural frequencies (for both longitudinal and transverse vibrations) have been obtained by means of a separate computer program employing standard techniques (see Appendix VI, Program VIBRAT). Flexural rigidities, longitudinal stiffness, and mass distribution are the input to this auxiliary program; these input data have been obtained from analyses performed by the manufacturer. The output of the auxiliary program becomes input for the simulator program and consists of normal mode shapes, natural frequencies, generalized masses, and, for the transverse vibration, normalized bending stresses.

Next, consider the load deformation input parameters for the structure. A double modulus relationship has been postulated between crushing force and structural deformation in the local area of contact between the ground and the aircraft. The crushing force moduli have been obtained by computing average local plastic buckling loads for those structural members that fail by local instability and by adding an appropriate percentage for the resistance offered by bending of longitudinal members. Based upon observed behavior of a plastically deformed structure, an estimate has

been made of plausible "springback" deformation associated with unloading. A range of 10- to 20- percent springback was postulated for a 2- to 3- foot depth of structural crushing in the region of the underside of the nose. The springback is obtained in the simulator program by employing a greater modulus for unloading as well as for initial loading below a critical force (marking the onset of plastic crushing).

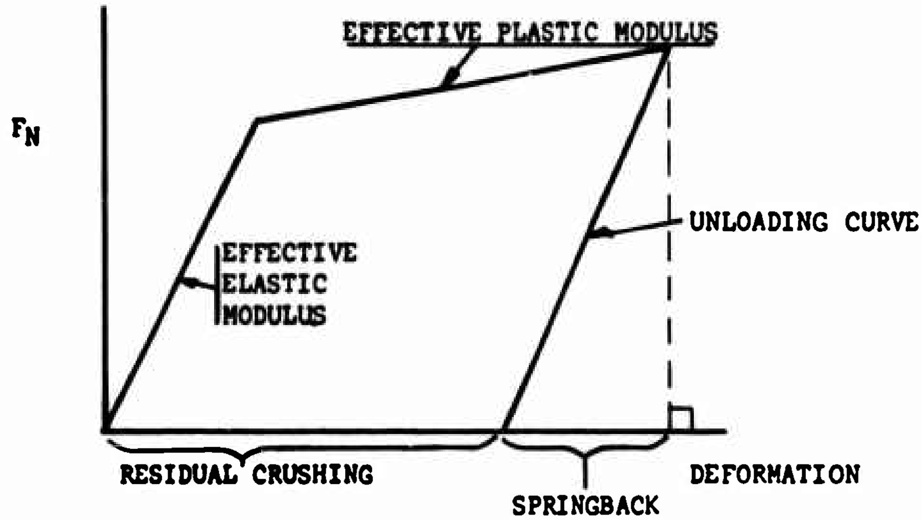


Figure 2. Plot of Normal Force Versus Structural Deformation

The onset of plastic crushing is signaled by a critical value of applied normal force (see Figure 2). This critical value is estimated considering those members that would first undergo general buckling; however, this value must also be consistent with the elastic modulus for deformation, the plastic modulus, and the assumed points through which the curves must pass.

The simulator program computes compressive bending stresses along the top of the fuselage for each time increment. When a critical effective buckling stress is reached at a given station, a "yield hinge" is considered to be formed in the fuselage and the mode of simulation changes. The critical fuselage buckling stress has been computed on the basis of the critical stress for a longitudinally stiffened curved panel. The computed value has been increased by an estimated factor to account for the dynamic overload capability associated with short-duration pulses and redistribution of stress as a plastic hinge is formed.

Once a yield hinge forms, a plastic-hinge moment offers substantially constant resistance to further bending at the hinge. This plastic-hinge moment has been computed on the basis of resistance offered to continuation of buckling and crushing of skin and longitudinal members.

In addition to the structural data described above, geometric input defining the longitudinal contour of the underside of the fuselage is required. These data were obtained from scale drawings provided by the manufacturer.

GROUND PARAMETERS

It should be noted that an accident can occur in a wide variety of soils whose properties may vary considerably. Consequently, the ground parameters were varied over practical ranges for a number of simulator runs.

The normal soil reaction force, F_N, was considered to be composed of several components. First, the essentially elastic behavior provides a contribution that increases with penetration. However, as both surface contact area and ground resistance per unit area are roughly proportional to depth of penetration, the assumed relationship is:

$$F_{N1} = C_1 Z_G^2$$

where

Z_G = ground penetration

C_1 = soil elastic modulus

The constant C_1 has been estimated for a typical soil.

A second contribution to normal force is associated with the phenomenon of planing (hydroplaning) is associated both with horizontal velocity and depth of soil penetration. The relationship is:

$$F_{N2} = C_2 Z_G \dot{X}$$

where

$\dot{X}$ = horizontal component of aircraft velocity

C_2 = planing parameter

The planing coefficient C_2 has been roughly estimated for various soils, based upon momentum exchange and soil compressive resistance. The degree to which the nose of the aircraft remains a "plane" as opposed to

a "scoop" would further affect this parameter. In the computer simulation runs, a range of practical values was used for this parameter.

The third contribution to the normal force component is that of the direct momentum exchange effect. As the aircraft penetrates the ground, it accelerates soil mass to its velocity. A momentum exchange relationship leads to

$$F_{N3} = C_3 \dot{Z}_G^2 Z_G^2$$

where

$\dot{Z}_G$ = time rate of soil penetration

C_3 = soil impact parameter

The parameter C_3 is approximately equal to the mass density of the soil multiplied by the contact area and divided by the penetration Z_G.

The total normal component is the sum of the three separate contributions:

$$F_N = F_{N1} + F_{N2} + F_{N3}$$

The tangential component of the soil reaction force is similarly composed of separate contributions. The first of these is simple friction.

$$F_{T1} = fF_N$$

where

f = coefficient of friction

To the extent that the soil has been penetrated and some manner of scoop has been formed at the nose of the aircraft, two additional contributions to the tangential force would exist. The first of these is associated with soil "drag" or "plowing" action and is proportional to the horizontal velocity and ground penetration:

$$F_{T2} = C_4 X \dot{Z}_G$$

The plowing coefficient for a given soil can only be determined experimentally. For this purpose a simple experiment was designed and conducted to provide a rough separation of the plowing and friction phenomena with two extremes of scoop conditions. The results of this

experiment were employed to provide order-of-magnitude values for the soil reaction parameters f, C_2, and C_4. The experiment is described in Appendix III. The other contribution associated directly with the scoop effect is the horizontal momentum exchange. It would thus vary with soil penetration and with the velocity squared; that is,

$$F_{T3} = C_5 \dot{X}^2 Z_G$$

The coefficient C_5 would depend upon effective scoop area and soil density and has been roughly computed. In simulation runs, this parameter will be varied considerably to simulate conditions ranging from a definite scoop in a freshly plowed field to the other extreme of planing over hardpan soil or a concrete ramp. The total tangential force is then the sum of the individual contributions:

$$F_T = F_{T1} + F_{T2} + F_{T3}$$

APPLICATION OF CRASH PULSE SIMULATOR

The CV-2 and CV-7 aircraft crash pulses were developed by the simulator program for combinations of the following parameters: velocity, sink rate, attitude angle at impact, soil conditions, and aircraft weight conditions.

1. Velocity was varied from 80 to 120 feet per second.
2. Sink rate was varied from 10 to 30 feet per second.
3. Attitude angle was varied from 3 to 15 degrees.
4. Two basic soil conditions were considered: hardpan, and a soft soil equivalent to a cultivated field.
5. For each aircraft, two weight conditions were considered: operational light and operational heavy.

A summary of significant results is contained in the following tables, which relate maximum cargo compartment acceleration (excluding short-duration peaks), time duration of pulse, and velocity change to the various input parameters.

An example input to the simulator program and developed output is contained in Appendix IV.

TABLE I
RESPONSE TO IMPACT VELOCITY

Velocity (ft/sec)	Soil Condition	Maximum Acceleration (G)	Pulse Duration (sec)	Velocity Change (ft/sec)
80	Hardpan	6.1	.138	12
100	Hardpan	6.4	.140	12
120	Hardpan	7.0	.144	13
80	Soft Soil	9.4	.188	26
100	Soft Soil	11.4	.200	33
120	Soft Soil	12.7	.220	42

CV-7 Aircraft, operational light.
Sink rate = 20 fps; impact angle = 12 degrees

TABLE II
RESPONSE TO SINK RATE

Sink Rate (ft/sec)	Soil Condition	Maximum Acceleration (G)	Pulse Duration (sec)	Velocity Change (ft/sec)
10	Hardpan	3.5	.126	7
20	Hardpan	6.4	.140	12
30	Hardpan	9.1	.266	26
10	Soft Soil	6.9	.248	26
20	Soft Soil	11.4	.200	33
30	Soft Soil	14.4	.268	54

CV-7 Aircraft, operational light.
Velocity = 100 fps; impact angle = 12 degrees

TABLE III
RESPONSE TO IMPACT ANGLE

Impact Angle (deg)	Soil Condition	Maximum Acceleration (G)	Pulse Duration (sec)	Velocity Change (ft/sec)
3	Hardpan	6.1	.126	11
9	Hardpan	6.2	.124	11
12	Hardpan	6.4	.140	12
15	Hardpan	7.2	.150	14
3	Soft Soil	9.0	.144	19
9	Soft Soil	10.6	.70	26
12	Soft Soil	11.4	.200	33
15	Soft Soil	12.2	.244	41

CV-7 Aircraft, operational light.
Velocity = 100 fps; sink rate = 20 fps

CARGO SIMULATOR

DESCRIPTION

The computer program to simulate cargo restraint systems is designed to obtain the dynamic response of a cargo retention system (employing) load limiters) to an applied acceleration pulse. The cargo simulation is accomplished not as a separate computer program but rather as a subroutine appended to the crash pulse simulator program. As the specific crash pulse is generated, it becomes input (internally) to the cargo simulation subroutine.

MATHEMATICAL MODEL

The cargo is assumed to rest on the cabin floor (with a suitable friction coefficient between cargo and floor), restrained fore and aft by load limiters as illustrated in Figure 3.

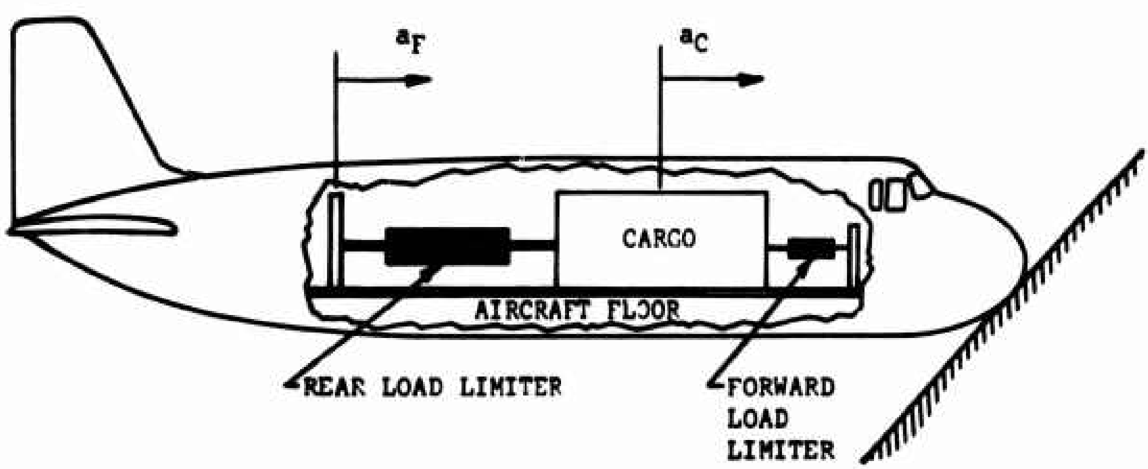


Figure 3. Cargo Restraint by Load Limiters

Each load limiter provides unidirectional restraint; the aft load limiter, for example, offers restraint to forward displacement of the cargo relative to the floor (when slack is taken up).

The longitudinal force applied to the cargo is transmitted from the aircraft through either the aft or the forward load limiter, as well as through the cargo floor by means of friction. The maximum value that this force may assume is the load-limiter limit force plus the coefficient of friction times the normal force between floor and cargo. (The normal floor force, in turn, depends upon the normal component of floor acceleration.)

At each time increment, the subroutine accepts as input the generated acceleration components (longitudinal and normal) of the floor at the cargo location. For the case of zero relative velocity (of cargo to floor), the cargo mass times the longitudinal acceleration is compared with the computed maximum possible longitudinal force. If the former is less than the computed limiting value, no relative acceleration occurs. Otherwise, the cargo acceleration is the computed limiting longitudinal force divided by cargo mass. The resulting relative acceleration is then the difference between the floor acceleration and the absolute cargo acceleration.

For the case in which the cargo has a relative velocity, the applied cargo force becomes the load-limiter load plus the computed friction force (assuming tie-down slack is not present). Again, the applied cargo force determines the absolute cargo acceleration and in turn the relative acceleration.

Numerical integration of the kinematic relationships is used to obtain relative cargo velocity and displacement (at each time increment) from the above-computed relative acceleration. The load-limiter stroke is finally obtained as the maximum cargo displacement.

A flow chart and computational relationships for the cargo simulation subroutine are given in Appendix II.

APPLICATION OF CARGO SIMULATION PROGRAM

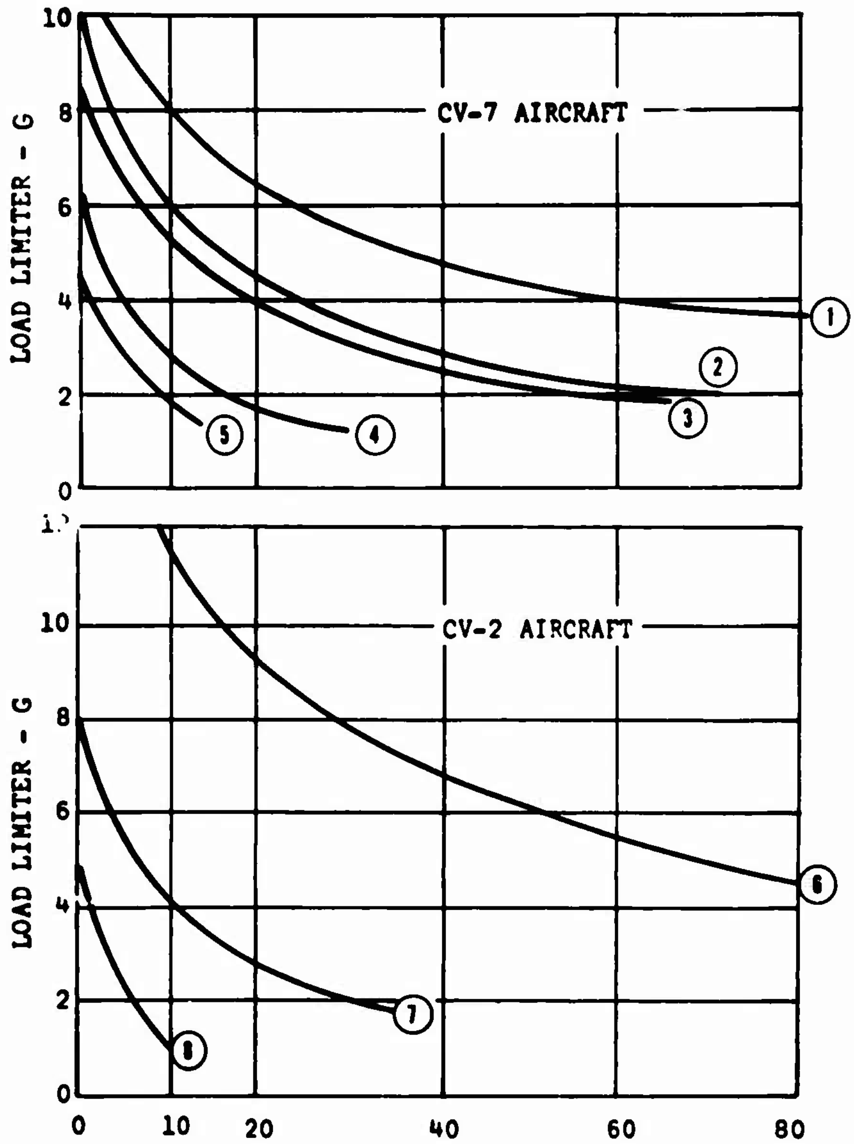
The cargo simulation program was employed for ten representative crash pulses (as shown in Table IV). For each pulse, the load-limiter stroke was computed for five different load-limiter limit forces, corresponding to 2G, 4G, 6G, 8G, and 10G limiting accelerations. The resulting limiter strokes are tabulated in Table IV along with the input conditions for each simulation run. (The center of the cargo compartment was selected as a representative location.)

A family of curves showing load-limiting force versus cargo displacement appears in Figure 4.

Appendix V shows typical output sheets from the cargo simulation program.

TABLE IV
RESULTS OF CARGO SIMULATION

Aircraft Configur-ation and Soil Condition	Velocity (ft/sec)	Sink Rate (ft/sec)	Impact Angle (deg)	Max. G (G)	Pulse Duration (sec)	Velocity Change (ft/sec)	Load Limiter (G)	Cargo Displ. (ft)
CV-2 Operational Light Soft Soil	120	30	15	20	.214	60	2	16.67
							4	7.66
							6	4.22
							8	2.41
							10	1.40
	90	20	9	11.6	.158	26	2	2.56
							4	0.91
							6	0.29
							8	0.08
							10	0.00
	80	10	6	5.67	.128	12	2	0.43
							4	0.05
							6	0.00
							8	0.00
							10	0.00
CV-7 Operational Heavy Hardpan	100	30	15	7.4	.300	25	2	1.33
							4	0.33
							6	0.05
							8	0.00
							10	0.00
	120	30	12	7.5	.300	27	2	1.28
							4	0.32
							6	0.03
							8	0.00
							10	0.00
	120	30	6	6.0	.240	21	2	0.68
							4	0.13
							6	0.00
							8	0.00
							10	0.00
CV-7 Operational Heavy Soft Soil	120	30	12	14.2	.300	64	2	13.10
							4	5.01
							6	2.04
							8	0.78
							10	0.21
	120	30	9	13.2	.198	37	2	5.20
							4	2.02
							6	0.84
							8	0.29
							10	0.08
	120	30	6	11.0	.242	44	2	4.67
							4	1.66
							6	0.55
							8	0.12
							10	0.01
CV-2 Operational Heavy Hardpan	80	30	3	8.6	.112	20	2	0.58
							4	0.18
							6	0.02
							8	0.00
							10	0.00



Legend	Weight Condition	Soil Condition	Velocity (ft/sec)	Sink Rate (ft/sec)	Impact Angle (deg)
(1)	Heavy	Soft Soil	120	30	12
(2)	Heavy	Soft Soil	120	30	9
(3)	Heavy	Soft Soil	120	30	6
(4)	Heavy	Hardpan	100	30	15
(5)	Heavy	Hardpan	120	30	6
(6)	Light	Soft Soil	120	30	15
(7)	Light	Soft Soil	90	20	9
(8)	Heavy	Hardpan	80	30	3

Figure 4. Plots of Load-Limiter Force Versus Cargo Displacement

RESULTS

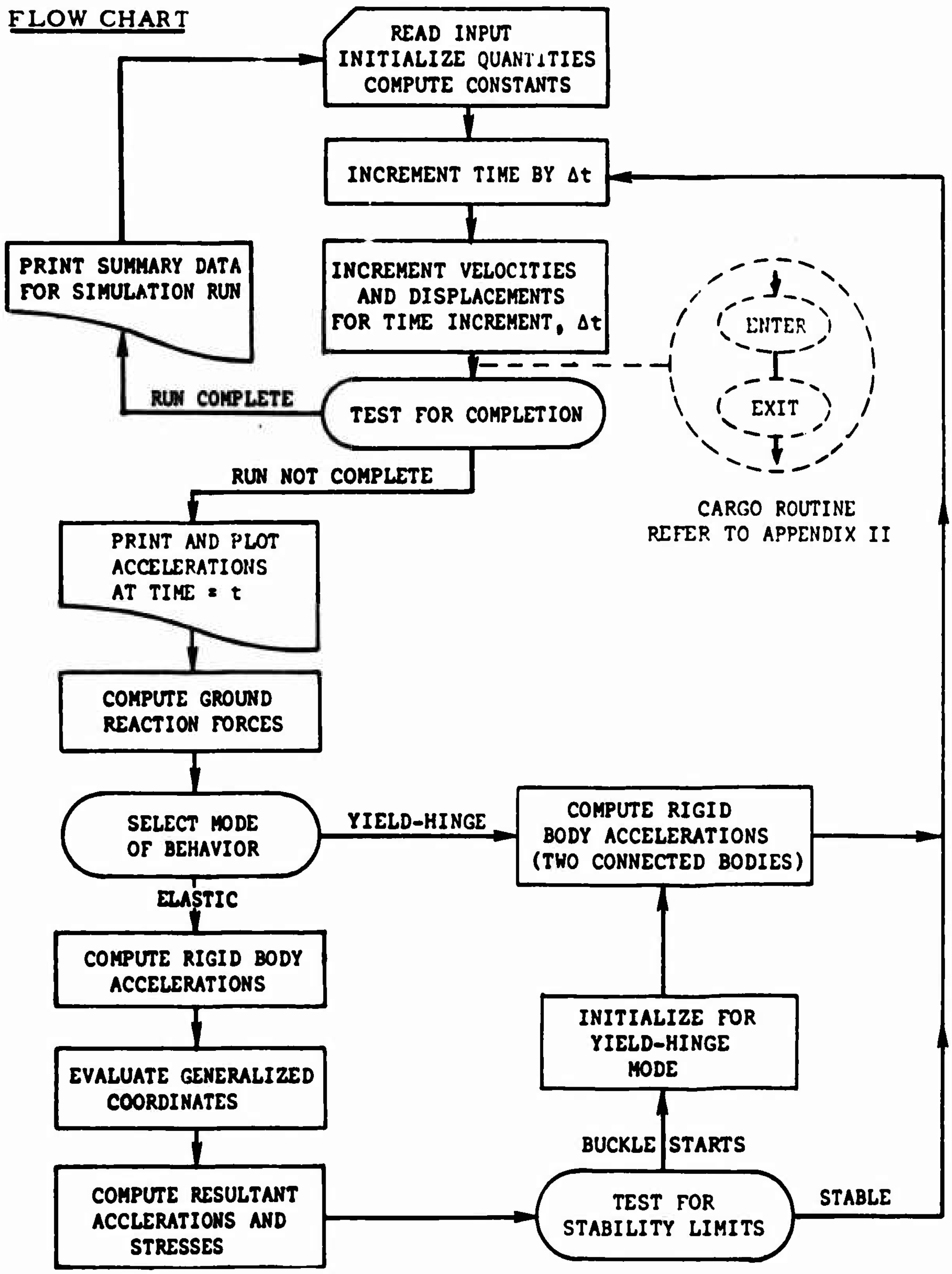
The investigation has led to the development of a crash pulse computer simulator (Appendix IV) providing an analytical tool for the study of crash pulse time histories of fixed-wing aircraft. This tool was applied to the CV-7 aircraft to obtain tabulated acceleration data (Tables I, II, III) for variations of pertinent input parameters, including soil conditions and accident configurations.

In addition, the investigation has led to the development of a cargo simulator program (Appendix V) to serve as an analytical tool to study cargo acceleration levels and displacements during a crash sequence. This simulator was applied to obtain tabular data and plots (Table IV and Figure 4) relating cargo displacements to load-limiter values for various crash conditions.

It should be pointed out that all of the acceleration-time pulses generated in this program fall within the human tolerance limits.

APPENDIX I

CRASH PULSE SIMULATOR



COMPUTATIONAL OPERATIONS (Refer to List of Symbols)

1. Geometric, structural, and soil parameters that depend upon the angle θ are computed as polynominals:

$$H_n = A_{n1} + A_{n2}\,\theta + A_{n3}\,\theta^2 + A_{n4}\,\theta^3$$

2. The coordinates x and y are found:

$$x = H_2 \sin\theta - (s_B - \frac{1}{H_1}) \cos\theta$$

$$y = (s_B - \frac{1}{H_1}) \sin\theta + H_2 \cos\theta$$

3. The interference, Z, and its time derivative, $\dot{Z}$, are found:

$$Z = Y - y \quad , \quad \dot{Z} = \Delta Z/\Delta t$$

4. The normal force, F_N is computed:

a. For positive $\dot{Z}$ and F_N less than critical F_N,

$$F_N = K_1 (Z - Z_G)$$

where

$$Z_G = \sqrt{\frac{K_1}{g} Z + B^2} - B$$

$$g = C_1 + (\dot{Z}_G)^2 C_2$$

$$\dot{Z}_G = \Delta Z_G/\Delta t$$

$$B = \frac{(1 - S_C) H_8 \dot{X} + K_1}{2g}$$

and

$$F_N \text{ critical} = \frac{1 + 8\theta^2}{H_6}$$

$$K_1 = \frac{1 + 4\theta^2}{H_3}$$

$$C_1 = \frac{1 + 4\theta^2}{H_4}$$

$$C_2 = \frac{1}{H_5}$$

$$S_C = \text{scoop factor (varying from 0 to 1)}$$

b. For $F_N > F_N$ critical, $\dot{Z}$ positive,

$$\Delta F_N = kK_1 (\Delta Z - \Delta Z_G)$$

where

$$\Delta Z_G = \frac{\Delta Z}{\left[2gZ_G + (1 - S_C) H_8 \dot{X} \right] kK_1 + 1}$$

$$k = \text{reduction factor for modulus } K_1$$

c. For $\dot{Z}$ negative,

$$\Delta F_N = K_1 (\Delta Z - \Delta Z_G)$$

where

$$\Delta Z_G = \Delta Z \frac{Z_G}{Z}$$

5. The tangential force is computed:

$$F_T = fF_N + S_C \left[H_8 \dot{X} + H_9 \dot{X}^2 \right] Z_G$$

where

$$f = \text{effective coefficient of friction}$$

6. Accelerations are computed:

$$\ddot{X} = F_N/m_A \quad , \quad \ddot{Y} = F_T/m_A$$

$$\ddot{\theta} = \left[F_N x + F_T \left(y + \frac{Z_G}{2}\right) \right] /I_A$$

where

$$m_A = \text{aircraft mass}$$

$$I_A = \text{aircraft mass moment of inertia}$$

7. Generalized forces for vibration modes are computed:

$$Q_1 = P\phi_1(s_J) + M\frac{d\phi_1}{d_s}(s_J) - \sum_i \bar{a}_i\mu_i\,\phi_1(s_i)$$

$$Q_2 = P\phi_2(s_J) + M\frac{d\phi_1}{ds}(s_J) - \sum_i \bar{a}_i\,\mu_i\,\phi_2(s_i)$$

$$Q_3 = C\phi_3(s_J) - \sum_i a_i\mu_i\,\phi_3(s_i)$$

$$Q_4 = C\phi_4(s_J) - \sum_i a_i\mu_i\,\phi_4(s_i)$$

where

$$P = F_N \cos\theta - F_T \sin\theta$$

$$C = F_T \cos\theta + F_N \sin\theta$$

$$M = C\left[(y + \frac{Z_G}{2})\sin\theta + x\cos\theta\right]$$

$\phi_1 \ldots \phi_4$ = normalized vibration modes as functions of s

s_J = distance along fuselage axis to center of force application (from nose)

$\bar{a}_i, a_i$ = rigid body acceleration components (transverse and longitudinal at station s_i

μ_i = mass associated with i^{th} finite subdivision of fuselage

8. Generalized coordinates are evaluated:

$$q_n(t+\Delta t) = \exp\left(-\frac{\beta}{2}\Delta t\right)\left\{q_n(t)\cos\bar{\omega}_n\Delta t + \left[h_n(t) + \frac{Q_n(t)\,\Delta t}{m_n\bar{\omega}_n}\right]\sin\bar{\omega}_n\Delta t\right\}$$

where

n = varies from 1 to 4

β = damping coefficient

m_n = generalized mass = $\int_0^L \mu\phi_n^{\,2}\,dx$

$$\bar{\omega}_n = \sqrt{\omega_n^2 - \frac{\beta^2}{4}}$$

$$\omega_n = \text{natural frequency}$$

and $h_n(t)$ is found from:

$$h_n(t + \Delta t) = \exp\left(-\frac{\beta}{2}\Delta t\right) \left\{ \left[h_n(t) + \frac{Q_n(t)\,\Delta t}{m_n \bar{\omega}_n}\right] \cos \bar{\omega}_n \Delta t - q_n(t) \sin \bar{\omega}_n \Delta t \right\}$$

9. The bending moment is computed:

$$M_B(s_i) = EI(s_i) \left[q_1 \frac{d^2 \phi_1}{ds^2}(s_i) + q_2 \frac{d^2 \phi_2}{ds^2}(s_i) \right]$$

where

$$EI(s_i) = \text{Flexural rigidity at } s = s_i$$

10. The longitudinal acceleration is computed

$$a_{Ti} = a_i + a_{Vi}$$

where

a_{Ti} = total longitudinal acceleration at $s = s_i$

a_i = rigid body acceleration at $s = s_i$

a_{Vi} = relative acceleration from longitudinal vibration

$$a_{Vi} = q_3 \frac{d^2 \phi_3}{dt^2}(s_i) + q_4 \frac{d^2 \phi_4}{dt^2}(s_i)$$

11. Components of velocity and displacements are computed from kinematic relationships:

$$\Delta \dot{X} = \left(\ddot{X} - \frac{\Delta \ddot{X}}{2}\right) \Delta t$$

where

$\ddot{X}$ = updated acceleration (that is, acceleration at end of time interval, Δt)

$\Delta \dot{Y}$, $\Delta \dot{\theta}$ are found similarly.

$$\Delta X = (\dot{X} - \frac{\Delta \dot{X}}{2})\Delta t$$

where $\dot{X}$ = updated velocity

ΔY, $\Delta\theta$ are found similarly.

12. For the "yield-hinge" mode of aircraft deformation, rigid body accelerations are computed as follows: The angular acceleration, $\ddot{\theta}_F$, of the forward portion of the aircraft and the angular acceleration, $\ddot{\theta}_R$, of the rear portion (aft of the yield hinge) are each computed:

$$\ddot{\theta}_F = \frac{G_3 \cdot G_5 - G_2 \cdot G_6}{\text{Den}}$$

$$\ddot{\theta}_F = \frac{G_1 \cdot G_6 - G_3 \cdot G_4}{\text{Den}}$$

where

$$G_1 = \left(\frac{I_F}{m_F} + \frac{m_R}{m_A} r_F^{\,2}\right)\frac{m_A}{m_F}$$

$$G_2 = G_4 \frac{m_R}{m_F}$$

$$G_3 = \frac{M_H m_A}{m_R m_F} + F_n\left(\frac{X_H m_A}{m_F^{\,2}} + \frac{D_{XF}}{m_F}\right) + F_T\left[\frac{\left(Y_H + \frac{Z}{2}\right)m_A}{m_F^{\,2}} - \frac{D_{YF}}{m_F}\right] + \frac{m_R}{m_F} G_D$$

$$G_4 = D_{XF} \cdot D_{XR} + D_{YF} \cdot D_{YR}$$

$$G_5 = \left(\frac{I_R}{m_R} + \frac{m_F}{m_A} r_R^{\,2}\right)\frac{m_F}{m_A}$$

$$G_6 = -\frac{M_H m_A}{m_R m_F} - F_n \frac{D_{XF}}{m_F} + F_T \frac{D_{YR}}{m_H} + G_D$$

$$\text{Den} = G_1 \cdot G_5 - G_4 \cdot G_2$$

$$G_D = D_{XR}(D_{YF} \cdot \dot{\theta}_F^2 + D_{YR} \cdot \dot{\theta}_R^2) - D_{YR}(D_{XF} \cdot \dot{\theta}_F^2 + D_{YF} \cdot \dot{\theta}_R^2)$$

I_F, I_R = mass moments of inertia

m_A, m_F, m_R = masses

X_H, Y_H = coordinates of yield hinge

M_H = yield-hinge moment

D_{XF} = $X_F - X_H$

X_F, Y_F = coordinates of forward center of gravity

D_{YF}, D_{XR}, D_{YR} = similar to D_{XF}

r_F^2 = $D_{XF}^2 + D_{YF}^2$

r_R^2 = similar to r_F^2

13. Acceleration components, $\ddot{X}_F, \ddot{Y}_F, \ddot{X}_R, \ddot{Y}_R$, of forward and aft section center of gravity are computed:

$$\ddot{X}_F = -\frac{F_T + m_R G_7}{m_A} - \frac{m_R}{m_A G_9}$$

$$\ddot{Y}_F = \frac{F_N - m_R G_8}{m_A} - \frac{m_R}{m_A G_{10}}$$

$$\ddot{X}_R = \frac{F_T - m_F G_7}{m_A} + \frac{m_F}{m_A G_9}$$

$$\ddot{Y}_R = \frac{F_n - m_F G_8}{m_A} + \frac{m_F}{m_A G_{10}}$$

where

$$G_7 = \dot{\theta}_F^2 D_{XF} + \dot{\theta}_R^2 D_{XR}$$

$$G_8 = \dot{\theta}_F^{\,2} D_{YF} + \dot{\theta}_R^{\,2} D_{YR}$$

$$G_9 = D_{YF} \cdot \ddot{\theta}_F + D_{YR} \cdot \ddot{\theta}_R$$

$$G_{10} = D_{YF} \cdot \ddot{\theta}_F + D_{YR} \cdot \ddot{\theta}_R$$

14. Velocity and displacement components are updated from kinematic relationships:

$$\dot{X}_F = (\ddot{X}_F - \frac{\Delta \ddot{X}_F}{2})\Delta t$$

where

$$\ddot{X}_F = \text{updated acceleration}$$

$\Delta \dot{Y}_F$, $\Delta \dot{\theta}_F$, $\Delta \dot{X}_R$, $\Delta \dot{Y}_R$, $\Delta \dot{\theta}_R$ are found similarly.

$$\Delta X_F = (\dot{X}_F - \frac{\Delta \dot{X}_F}{2})\Delta t$$

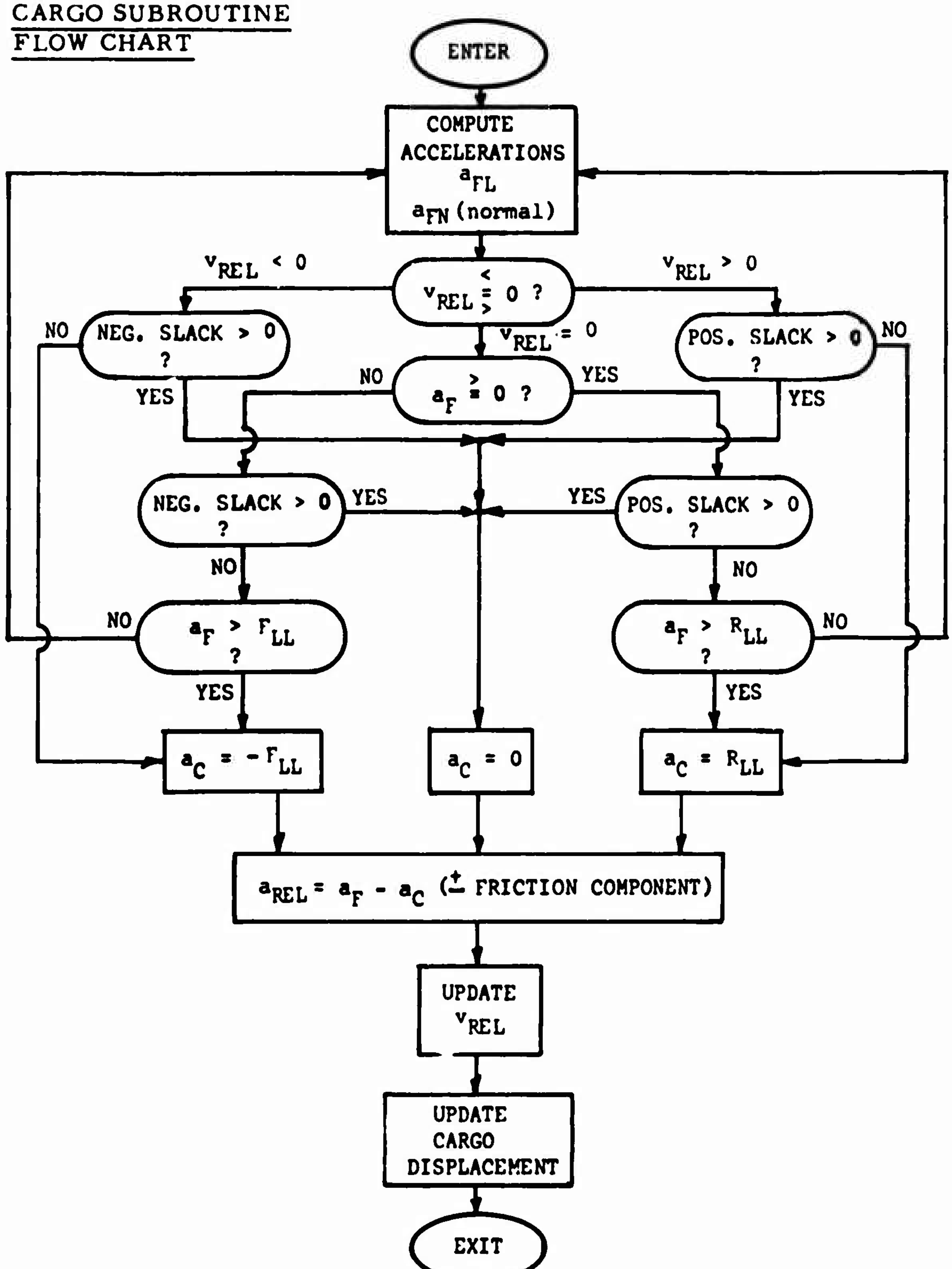
where

$$\dot{X}_F = \text{updated velocity}$$

ΔY_F, $\Delta\theta_F$, ΔX_R, ΔY_R, $\Delta\theta_R$ are found similarly.

APPENDIX II
CARGO SIMULATOR

CARGO SUBROUTINE
FLOW CHART



COMPUTATIONAL OPERATIONS FOR CARGO SUBROUTINE

1. Longitudinal acceleration is computed by crash pulse program.

2. Normal acceleration (augmented by an equivalent acceleration for weight) is computed:

$$a_{FN} = \ddot{X} \sin\theta + \ddot{Y} \cos\theta - \ddot{\theta} s_J + 32.2 \cos\theta$$

where

s_J = Distance from center of gravity to the cargo location

3. If cargo relative velocity (relative to the floor) is zero at beginning of time interval Δt, cargo acceleration is computed as follows:

$$a_C = a_F \quad \text{for } (-F_{LL} - f_C a_{FN}) < a_F < (R_{LL} + f_C a_{FN})$$

$$a_C = -F_{LL} - f_C a_{FN} \quad \text{for } a_F < \left(-F_{LL} - f_C a_{FN}\right)$$

$$a_C = R_{LL} + f_C a_{FN} \quad \text{for } a_F > \left(R_{LL} + f_C a_{FN}\right)$$

where

a_C = cargo acceleration

a_F = floor acceleration (longitudinal)

a_{FN} = Floor acceleration (normal)

f_C = coefficient of friction between floor and cargo

R_{LL} = rear load-limiter limit load (in the form of equivalent cargo acceleration)

F_{LL} = forward load-limiter limit load (equivalent acceleration)

4. If the cargo has a relative velocity, cargo acceleration is computed as follows:

$$a_C = R_{LL} + f_C a_{FN} \quad \text{for } v_{REL} > 0 \text{ and no slack}$$

$$a_C = -F_{LL} - f_C a_{FN} \quad \text{for } v_{REL} < 0 \text{ and no slack}$$

5. If slack is present in system, the cargo acceleration is:

$$a_C = a_F \quad \text{for } -f_C a_{FN} < a_F < f_C a_{FN}$$

$$a_C = -f_C a_{FN} \quad \text{for } a_F < -f_C a_{FN}$$

$$a_C = f_C a_{FN} \quad \text{for } a_F > +f_C a_{FN}$$

6. The relative cargo acceleration is computed as:

$$a_{REL} = a_F - a_C$$

with a_{REL} taken positive in the forward direction but a_F and a_C positive in the aft direction.

7. Relative velocity and relative displacement are computed by numerical integration:

$$\Delta v_{REL} = \left(a_{REL} - \frac{\Delta a_{REL}}{2}\right) \Delta t$$

$$\Delta s_{REL} = \left(v_{REL} - \frac{\Delta v_{REL}}{2}\right) \Delta t$$

where

s_{REL} = relative (forward) displacement of cargo

v_{REL} = relative (forward) velocity of cargo

APPENDIX III

SOIL DRAG EXPERIMENT

An experiment designed to separate phenomena involved in the longitudinal resistance offered by the soil (during a crash) and to establish relative magnitudes of significant parameters was conducted using a typical clay-sand soil.

DESCRIPTION

An instrumented "shoe" was attached to the underside of a heavy cart. The cart was towed at various speeds over a trough of prepared soil, with the shoe set at a level for a given penetration of the soil. (See Figure 5.)

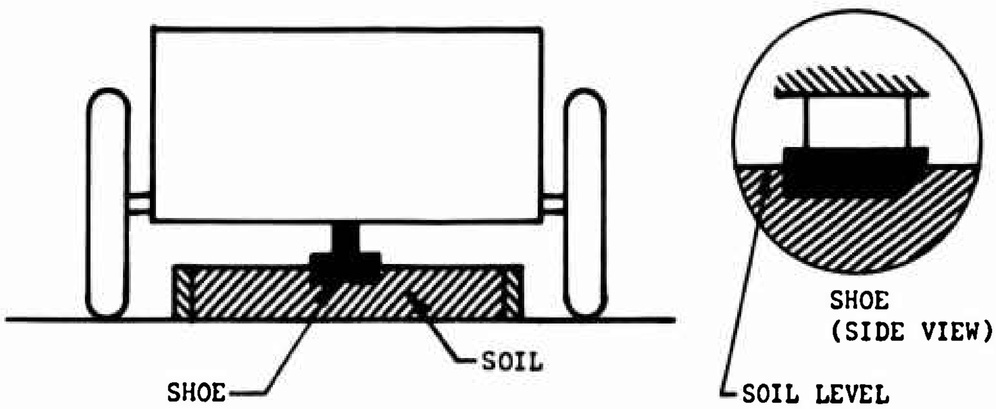


Figure 5. Soil Drag Experiment.

Instrumentation provided a history of normal and tangential forces for each run. Six runs were accomplished (and duplicated); they consisted of three velocities with the shoe orientated in each direction, i. e., with the sloped edge forward and the blunt edge forward.

The results are tabulated as follows:

TABLE V
EXPERIMENTAL DATA

Velocity (fps)	Shoe Orientation	Tangential Force (lb)	Normal Force (lb)
4	Slope Forward	550	800
22	Slope Forward	520	700
38	Slope Forward	750	750
4	Blunt Forward	500	550
22	Blunt Forward	400	400
38	Blunt Forward	450	350

If a mathematical model for the tangential force is postulated as

$$F_T = fF_N + \nu A_s \dot{X},$$

ranges for the coefficients f and ν may be computed consistent with the above data. These ranges are found to be:

f varies from .3 to .9

ν varies from 10 to 46 (lb-sec/ft^3)

where

A_s is the total contact surface (ft^2)

INPUT NOTATION FOR COMPUTER PROGRAMS

INPUT NOTATION		
A(I, J)	-	(I=1, 3; J=1, 4) Coefficients describing contour coordinates (ft)
A(I, J)	-	(I=3, 9; J=1, 4) Coefficients describing ground-aircraft interaction
AS(J)	-	Area of structural cross section (ft^2)
BETA	-	Longitudinal vibration damping factor
CDTH	-	Critical angle of plastic hinge rotation (rad)
CIA	-	Mass moment of inertia of aircraft about "Y" axis (slug ft^2)
CIM(J)	-	Mass moment of inertia per section (slug ft^2)
CLN	-	Station for cargo attachment
CMA	-	Total mass of aircraft (ft-lb)
CMU(J)	-	Mass per section (lb sec^2/ft)
CM(I)	-	(I=1, 4) Generalized masses (lb sec^2/ft)
CNS, NS	-	Number of fuselage sections
DF(J)	-	Fuselage depth from longitudinal axis (ft)
DS	-	Length of a section (ft)
DT	-	Time increment (sec)
ECA(J) ECB(J)	-	Normalized stresses for first and second bending vibration modes (lb/ft^2)
EC(J)	-	Structural parameter (lb/ft)
EI(J)	-	Flexural rigidity of fuselage (lb ft^2)

EPS	-	Error factor
FLL	-	Forward load-limiter limit acceleration (G)
FMU	-	Friction coefficient
MSW	-	Program switch code
OM(J)	-	Frequencies of vibrations (rad/sec)
PH1(J) PH2(J) PH3(J) PH4(J)	-	Normalized deflections of first and second vibration modes
RLL	-	Rear load-limiter limit acceleration (G)
RPM	-	Reduction factor to plastic-hinge moment
SB	-	Location of center of gravity (ft)
SNK	-	Sink velocity of aircraft (ft/sec)
STRB	-	Buckling stress (lb/ft^2)
THT	-	Angle of impact (rad)
THTD	-	Angular velocity (rad/sec)
VEL	-	Velocity at aircraft (ft/sec)
ZM(J)	-	Section moduli (ft^3)

APPENDIX IV
CRASH PULSE SIMULATOR FORTRAN LISTING

```
      PROGRAM CRASH
      DIMENSION V(10),PV(10),A(9,4),H(9),WDD(30),Q(20),
     1PQ(20),PH1(32),PH2(32),PH3(32),PH4(32),CMU(32),ECA(32),ECB(32)
     1DF(32),CIM(32),AC(32),U(2),PU(2),
     1OM(4),CM(4),SND(4),CSD(4),CMOM(4),PLOT(71),BT(4),QMX(4),ZM(32),
   10 FORMAT(8F10.6)
      READ 10, VFL,SNK,THT,THTD
      READ 10, ((A(I,J),J=1,4),I=1,9)
      READ 10,CMA,CIA,SP,STRB,CDTH,RPM,CNS,DS,FMU,DT
      READ 10,CMU,CIM,DF,PH1,PH2,PH3,PH4,ECA,ECB,ZM
      READ 10,OM,CM,BETA
      READ 300,(PLOT(J),J=1,71),BLNK,PRD,AST,EQ,PLS
  300 FORMAT (71A1,5A1)
      READ 9,MNTH,NDAY,NYR,NRUN
    9 FORMAT (4I5)
      SC=.75
   11 DO 12,J=1,10
   12 V(J)=0.
      V(3)=THT
      V(4)=SQRTF(VEL*VFL-SNK*SNK)
      V(5)=-SNK
      V(6)=THTD
      DO 14 I=1,2
   14 V(I) = A(I,1)+THT*(A(I,2)+THT*(A(I,3)+THT*A(I,4)))
      FN=9.
      IF (THT) 70,71,71
   70 V(1)=1./(1./A(1,1)-600.*THT)
   71 T1=SB-1./V(1)
      T2=V(2)*SINF(THT)-T1*COSF(THT)
      V(2)=V(2)*COSF(THT)+T1*SINF(THT)
      V(1)=T2
      FT=FN
      MXT=1
      NCR=1
      MRTN=1
      THTP = THT
      DO 17 I=3,9
   17 H(I) = A(I,1)+THT*(A(I,2)+THT*(A(I,3)+THT*A(I,4)))
      H3P=H(3)/(1.+4.*THT*THT)
      H4P=(1.+4.*THT*THT)/H(4)
      H5P = H(5)
      H6P=H(6)/(1.+8.*THT*THT)
      H7P=H(8)
      H8P=H(9)
      H1P=V(1)
      DO 13 J = 1,20
   13 Q(J)=0.
      T=0.
```

```
      NS=CNS
      OM(3) = OM(3) - BETA * BETA/4.0
      OM(4) = OM(4) - BETA * BETA/4.0
      DO 15 I = 1,4
      OMX(I)=0.
      CMOM(I)=SQRTF(OM(I))*CM(I)
      SND(I)=SINF(SQRTF(OM(I))*DT)
   15 CSD(I)=COSF(SQRTF(OM(I))*DT)
      SWCH= -1.0
      DO 301 J = 1,NS
  301 AC(J) = 0.
      DO 16 I = 3,4
      SND (I) = EXPF(-BETA/2. * DT) * SND(I)
   16 CSD(I) = EXPF(-BETA/2. * DT) * CSD(I)
      BT(1)=0.
      BT(2)=0.
      BT(3)=BETA
      BT(4)=BETA
      ZG = 0.
      FNC = 0.0
      FC=5.0
      FU = 2.0
      SH=40.
      ZDG = 0.
      ZGM = 0.
      STRM = 0.
      PRINT 200,MNTH,NDAY,NYR,NRUN
  200 FORMAT(1H1,20X,6H DATE ,3I4,20X,5H RUN ,I5//)
      PRINT 201
  201 FORMAT(5X,48H TIME    STA. A   STA. B   STA. C  (ACCEL. G UNITS)/)
      MSW = 1
      STRL=0.
      DO 112 I=1,3
  112 V(I)=V(3+I)*DT+V(I)
  110 PFN=FN
      DO 111 I=1,10
  111 PV(I)=V(I)
      THT=V(3)
      DO 113 I=1,9
  113 H(I)=A(I,1)+THT*(A(I,2)+THT*(A(I,3)+THT*A(I,4)))
      IF (THT) 117,118,118
  117 H(1)=SH
  118 T1=SB-1./H(1)
      H(4)=1./H(4)
      T2=H(2)*SINF(THT)-T1*COSF(THT)
      H(2)=H(2)*COSF(THT)+T1*SINF(THT)
      H(1)=T2
      V(10)=H(2)-V(2)
      ZD=(V(10)-PV(10))/DT
      Z=V(10)
```

```
127  IF(T-.3) 130,700,700
180  IF(V(4)) 114,114,181
181  IF(Z) 114,114,182
182  IF(V(3)-.8) 115,700,700
114  PRINT 116
116  FORMAT(18H REBOUND COMPLETE )
     GO TO 700
115  SWCH = -1.0 * SWCH
     IF (SWCH) 318,321,322
321  STOP
322  GA=AC(8)/32.2
     N=GA+21.5
     IF (N) 302,302,303
303  IF (N-71) 304,304,302
304  PLOT (N) = AST
302  GB=AC(13)/32.2
     K = GB + 26.5
     IF (K) 305,305,306
306  IF (K-71) 307,307,305
307  PLOT (K) = EQ
305  GC=AC(18)/32.2
     L=GC+31.5
     IF (L) 308,308,309
309  IF (L-71) 310,310,308
310  PLOT (L) = PLS
308  PLOT (26) = PRD
     PLOT(21)=PRD
     PLOT(31)=PRD
     PRINT 311,T,GA,GB,GC,PLOT
311  FORMAT (5X,F5.3,3F8.2,71A1)
     IF (N) 312,312,313
313  IF (N-71) 314,314,312
314  PLOT (N) = BLNK
312  IF (K) 315,315,316
316  IF (K-71) 317,317,315
317  PLOT (K) = BLNK
315  IF (L) 318,318,319
319  IF (L-71) 320,320,318
320  PLOT (L) = BLNK
318  CONTINUE
 30  DZ=ZD*DT
     COF=1.+4.*THT*THT
     H(3)=H(3)/COF
     H(4)=H(4)*COF
     H(6)=H(6)/(2.*COF-1.)
     IF(ZG - ZGM) 411,411,412
412  ZGM=ZG
     ZSP=Z-ZG
411  PZG = ZG
     IF (DZ) 119,120,120
```

```
120 GO TO (800,801), MSW
800 FUH=H(4)+ZDG * ZDG/H(5)
    CK=((1.0-SC)*H(8)*V(4)+1.0/H(3))/(2.0 * FUH)
    ZG=SQRTF(Z/(H(3)*FUH)+CK*CK)-CK
    ZS = Z - ZG
    FN = ZS/H(3)
    IF (FN-1./H(6)) 803,803,802
802 MSW = 2
801 FUH = H(4) + ZDG * ZDG /H(5)
    IF (FN - 1./H(6)) 804,805,805
804 FCH = H(3)
    GO TO 806
805 FCH = FC * H(3)
806 DZG=DZ/((2.*FUH*ZG+(1.-SC)*H(8)*V(4))*FCH+1.0)
899 ZG=ZG+DZG
    DZS = DZ - DZG
    DFN = DZS/FCH
    FN=PFN+DFN
    GO TO 803
119 DZG=DZ*ZG/(Z-DZ)
    FCH = H(3)
    GO TO 899
803 FNSC=(1.-SC)*H(8)*V(4)*ZG
    IF (FN-FNSC) 808,121,121
808 FN=FNSC
121 FT = FMU * FN + (H(8) * V(4) + H(9) * V(4) * V(4)) * ZG * SC
    ZDG = (ZG - PZG)/DT
    CTH=COSF(V(3))
    STH=SINF(V(3))
    P= FN*CTH-FT*STH
    C = FT * CTH + FN * STH
123 GO TO (126,165),MRTN
126 V(7)=-FT/CMA
    PNCR = NCR
    V(8)= FN/CMA
    V(9)=(FN*H(1)+FT*(V(2)+ZG/2.))/CIA
    DO 130 I=1,3
    V(3+I)= V(3+I)+(V(6+I)+PV(6+I))*DT/2.
130 V(I)=V(I)+(V(3+I)+PV(3+I))*DT/2.
    SJ=DS/2.
    DO 131 J=1,NS
    WDD(J)=V(7)*STH+V(8)*CTH-V(9)*(SB-SJ)
131 SJ=SJ+DS
    DO 132 I = 1,20
132 PQ(I)=Q(I)
    SP=SB-(V(2)+ZG/2.)*STH+H(1)*CTH
    CMM=C*((V(2)+ZG/2.)*CTH+H(1)*STH)
    J=SP/DS+1.0
    Q(1) = P * PH1(J) + CMM * (PH1(J+1)-PH1(J))/DS
    Q(2) = P* PH2(J) + CMM * (PH2(J+1)-PH2(J))/DS
```

```
      Q(3)=C*PH3(J)
      Q(4)=C*PH4(J)
      ACFL = V(8) * STH - V(7) * CTH
      SJ = SB - DS/2.
      THSQ=V(6)*V(6)
      DO 133 J=1,NS
      Q(1) = Q(1)-CMU(J)*WDD(J)*PH1(J)
      Q(2) = Q(2)-CMU(J)*WDD(J)*PH2(J)
      Q(3) = Q(3) - CMU(J) * (ACFL + THSQ * SJ) * PH3(J)
      Q(4) = Q(4) - CMU(J) * (ACFL + THSQ * SJ) * PH4(J)
  133 SJ = SJ - DS
      DO 212 I = 1,4
      IF(T-DT/2.) 210,210,211
  210 Q(4 + I) = Q(I) * DT * DT/(6. * CM(I))
      Q(16 + I) = Q(4 + I) *3./(SQRTF(OM(I)) * DT)
      GO TO 213
  211 QT = PQ(16 + I) + PQ(I)/CMOM(I)*DT
      Q(4 + I) = PQ(4 + I) * CSD(I) + QT * SND(I)
      Q(16 + I) = QT * CSD(I) - PQ(4 + I) * SND(I)
  213 Q(12+I)=Q(I)/CM(I)-(OM(I)+BT(I)*BT(I)/4.)*Q(4+I)-BT(I)*PQ(8+I)
      IF(ABSF(Q(4+I))-QMX(I)) 212,212,214
  214 QMX(I)=ABSF(Q(4+I))
  212 Q(8 + I) = PQ(8 + I) + (Q(12 + I) + PQ(12 + I)) * DT/2.0
      PSTR=0.
      PPSTR=0.
      CMNT = CMA - CMU(1)/2.0
      SJ = SB - DS/2.
      PSHR=0.
      BMM=-CMM
      NPP=1
      DO 400 J = 1,NS
      AC(J)=ACFL+THSQ*SJ+Q(15)*PH3(J)+Q(16)*PH4(J)
      GO TO (143,144), MXT
  143 ACN=V(7)*STH+V(8)*CTH-V(9)*SJ
      SHR=PSHR+CMU(J)*ACN
      GO TO(401,402),NPP
  401 IF (SP-SB+SJ-DS/2.) 403,403,402
  403 NPP=2
      SHR=SHR-P
  402 BMM=BMM-(PSHR+SHR)*DS/2.+CIM(J)*V(9)
      PSHR=SHR
      STR=ECA(J)*Q(5)+ECB(J)*Q(6)
      STRN=(3.*STR+6.*PSTR-PPSTR)/8.
      IF(STRL-STRN) 191,191,190
  190 STRL=STRN
      JSTL=J
  191 IF(STRN-STRM) 413,414,414
  414 STRM = STRN
      JST=J
  413 IF(STRN - STRB) 140,141,141
```

```
140 PPSTR=PSTR
    PSTR=STR
    GO TO 144
141 JH=J-1
    SH =, SB - SJ -DS/2.0
    PRINT 142,JH
142 FORMAT(21H YIELD HINGE AT STA. ,I3)
    MXT=2
144 CMNT = CMNT -(CMU(J) + CMU(J + 1))/2.0
400 SJ = SJ - DS
145 FORMAT (1X,10F11.4/)
    T=T+DT
    GO TO (110,149),MXT
149 CMF=0.
    T=T-DT
    DO 150 N=1,JH
150 CMF=CMF+CMU(N)
    CMR=CMA-CMF
    CLM=CMR/CMA
    TM=CMF/CMA
    RM=CMR/CMF
    SJ=DS/2.
    SBF=0.

    DO 152 N=1,JH
    SBF=SBF+CMU(N)*SJ
152 SJ=SJ+DS
    SBF=SBF/CMF
    SBR=(CMA*SB-CMF*SBF)/CMR
    DSF=SB-SBF
    DSR=SBR-SB
    U(1)=V(1)+DSF*CTH
    U(2)=V(2)-DSF*STH
    U(3)=V(3)
    U(4)=V(1)-DSR*CTH
    U(5)=V(2)+DSR*STH
    U(6)=V(3)
    DO 151 I=1,3
    U(6+I)=V(3+I)
    U(9+I)=V(3+I)
    U(12+I)=V(6+I)
151 U(15+I)=V(6+I)
    U(19)=V(1)+(SB-SH)*CTH-DF(JH)*STH
    U(20)=V(2)-(SB-SH)*STH-DF(JH)*CTH
    U(21)=V(10)
    RF=(SBF-SH)*(SBF-SH)+DF(JH)*DF(JH)
    RR=(SBR-SH)*(SBR-SH)+DF(JH)*DF(JH)
    SJ=DS/2.
    CIF=0.
    DO 153 N=1,JH
```

```
      CIF=CIF+CIM(N)+CMU(N)*SJ*SJ
  153 SJ=SJ+DS
      CIF=CIF-CMF*SBF*SBF
      CIR=CIA-CIF-CMF*(SB-SBF)*(SB-SBF)-CMR*(SB-SBR)*(SB-SBR)
      G1=(CIF/CMF+CLM*RF)/TM
      G5=(CIR/CMR+TM*RR)/TM
      DXF=U(1)-U(19)
      DYF=U(20)-U(2)
      MRTN=2
      DTH=0.
  160 PDTH = DTH
      PFN=FN
      DO 161 I=1,21
  161 PU(I)=U(I)
      DO 162 I=1,6
      U(6+I)=U(6+I)+(U(12+I)+PU(12+I))*DT/2.
  162 U(I) = PU(I) + (U(6+I) + PU(6+I))*DT/2.
      THT=U(3)
      DO 163 I=1,9
  163 H(I)=A(I,1)+THT*(A(I,2)+THT*(A(I,3)+THT*A(I,4)))
      STH=SINF(THT)
      CTH=COSF(THT)
      IF (THT) 157,158,158
  157 H(1)=SH
  158 T1=SB-1./H(1)
      H(4)=1./H(4)
      T2=H(2)*STH-T1*CTH
      H(2)=H(2)*CTH+T1*STH
      H(1)=T2
      STHR=SINF(U(6))
      CTHR=COSF(U(6))
      U(21)=H(2)-DSF*STH-U(2)
      Z=U(21)
      ZD=(U(21)-PU(21))/DT
      DO 164 I=1,2
      U(19)=PU(19)+(U(7)+PU(7)+(U(9)+PU(9))*DYF)*DT/2.
      U(20)=PU(20)+(U(8)+PU(8)+(U(9)+PU(9))*DXF)*DT/2.
      DXF=U(1)-U(19)
      DYF=U(20)-U(2)
      DXR=U(19)-U(4)
  164 DYR=U(5)-U(20)
      V(1) = U(1)
      V(2) = U(2)
      V(3)=U(3)
      V(4)=U(7)
      V(5) = U(8)
      V(6) = U(9)
      T=T+DT
      GO TO 127
  165 DTH=U(6)-U(3)
```

```
      IF(ABSF(DTH)-CDTH) 166,167,167
  167 PRINT 168
  168 FORMAT (15H FUSELAGE BREAK)
      GO TO 700
  166 PHM=STRB*ZM(JH)*(.5-11.1*DTH*DTH)
      IF(DTH-PDTH) 169,171,171
  169 PHM=-RPM*PHM
  171 G4=(DXF*DXR+DYF*DYR)
      G2=G4*RM
      F1=U(9)*U(9)
      F2=U(12)*U(12)
      F3=DXR*(F1*DYF+F2*DYR)-DYR*(F1*DXF+F2*DXR)
      G3=PHM/(CMF*TM)+FN*(U(19)/(CMF*TM)+DXF/CMF)+FT*((U(20)+.5*Z)/
     1(CMF*TM)-DYF/CMF)+RM*F3
      G6=-PHM/(CMR*TM)-FN*DXF/CMF+FT*DYR/CMF+F3
      DEN=G1*G5-G4*G2
      U(15)=(G3*G5-G2*G6)/DEN
      U(18)=(G1*G6-G3*G4)/DEN
      F4=F1*DXF+F2*DXR
      F5=F1*DYF+F2*DYR
      F6=DYF*U(15)
      F7=DYR*U(18)
      F8=DXF*U(15)
      F9=DXR*U(18)
      U(13)=-(FT+CMR*F4)/CMA-CLM*(F6+F7)
      U(16)=-(FT-CMF*F4)/CMA+TM*(F6+F7)
      U(14)=(FN+CMR*F5)/CMA-CLM*(F8+F9)
      U(17)=(FN-CMF*F5)/CMA+TM*(F8+F9)
      SJ=DS/2.
      DO 173 J=1,NS
      IF (J-JH) 174,174,175
  174 AC(J)=-U(13)*CTH+U(14)*STH+U(9)*U(9)*(SBF-SJ)
      GO TO 173
  175 AC(J)=-U(16)*CTHR+U(17)*STHR+U(12)*U(12)*(SBR-SJ)
  173 SJ=SJ+DS
      GO TO 160
  700 PRINT 203, NRUN
  203 FORMAT(1H1,20X,15H INPUT DATA RUN,I5//)
      PRINT 204,VEL,SNK,THTP,FMU
  204 FORMAT(4H VEL,F7.2,6X,4H SNK,F6.2,
     16X,4H THT,F6.3,6X,11H FRICT COFF,F5.2/)
      PRINT 205,STRB,CDTH,BETA
  205 FORMAT(11H CR STRESS ,F10.3,6X,7H CR ANG,F6.3,6X,
     112H DAMP FACTOR,F7.3/)
      PRINT 206,H3P,H4P,H5P
  206 FORMAT(8H FN1=ZS/,E10.4,10X,11H FN2=ZG*ZG*,E10.4,10X,
     116H FN3=ZG*ZGD*ZGD/,E10.4/)
      PRINT 207,H6P,H7P,H8P
  207 FORMAT (7H FNC=1/,F10.4,10X,11H FT1=XD*ZG*,F10.4,10X,
     114H FT2=XD*XD*ZG*,E10.4//)
```

```
      PRINT 208
  208 FORMAT(20X,15H DEVELOPED DATA//)
      PRINT 209,(V(I),I=1,6)
  209 FORMAT(3H X  ,F7.2,5X,3H Y  ,F6.2,5X,6H THETA,F6.2,5X5H XDOT,F7.2,
     15X,5H YDOT,F7.2,5X,9H THETADOT,F6.2/)
      ZS=ZSP
      GL=V(1)-HIP
      PRINT 410,ZG,ZS,ZGM,GL,STRM
  410 FORMAT(12H GRND DEFORM,F5.2,5X,9H FUS DEFL,F5.2,5X,
     115H MAX GRND DEFRM,F6.2,5X,7H GROOVE,F7.2,5X,10H MAXSTRESS,E9.2/)
      PRINT 409,(QMX(I),I=1,4),JST
  409 FORMAT(29H GENERALIZED COORDINATES   Q1=,F10.5,3X,4H Q2=,F10.5,3X,
     14H Q3=,F10.5,3X,4H Q4=,F10.5,3X,12H MAX STR LOC,I5)
      STRL=ABSF(STRL)
      PRINT 192,STRL,JSTL
  192 FORMAT (10X,16H MAX TENS STRESS,E9.2,3X,16H LOCATION NUMBER,I5)
      PRINT 40
   40 FORMAT (1H1,11H INPUT DATA)
      PRINT 145,((A(I,J),J=1,4),I=1,9)
      PRINT 145, FC,SC
      PRINT 145, CMA,CIA,SP,STRB,CDTH,RPM,CNS,DS,FMU,DT
      NRUN=NRUN+1
      READ 10,VEL,SNK,THT
      IF(EOF,60) 999,11
  999 STOP
      END
```

INPUT DATA FOR CRASH PULSE SIMULATOR

Aircraft - CV-7 (Operational Light)

VEL = 120.0

SNK = 20.0

THT = 0.2094

THTD = 0.

A(I, J):

A(I, J)

	1	2	3	4
1	.03704	3.1196	-8.557	11.005
2	4.64	-1.672	0.0	0.0
3	8.0×10^{-7}	0.0	8.0×10^{-6}	0.0
4	1.924×10^{-7}	0.0	33.6×10^{-6}	0.0
5	8.0×10^{-4}	0.0	135.0×10^{-4}	0.0
6	2.0×10^{-5}	0.0	42.2×10^{-5}	0.0
7	0.0	0.0	0.0	0.0
8	40000.	-2400.	0.0	0.0
9	20.0	0.0	0.0	0.0

CMA = 900.0

CIA = 1.53×10^{5}

SB = 27.0

STRB = 7.0×10^{7}

CDTH = 0.30

RPM = .50

CNS = 26.0

BETA = 40.0

DS = 26.

FMU = 0.75

DT = .001

<u>OUTPUT OF PROGRAM VIBRAT (REFER TO APPENDIX VI)</u>

CMU, CIM, AS, DF:

	CMU	CIM	ZM	DF
1	9.0	200	.050	2.0
2	24.5	250	.050	3.0
3	28.5	480	.050	4.0
4	24.5	390	.0608	4.5
5	14.0	250	.1544	4.5
6	8.9	250	.1831	4.5
7	19.0	254	.1821	4.5
8	211.3	340	.1731	4.5
9	210.3	250	.288	4.5
10	208.0	198	.252	4.5
11	18.5	240	.2375	4.5
12	19.5	380	.2282	4.5
13	22.0	413	.242	4.5
14	10.0	320	.1748	4.5
15	8.0	310	.180	3.30
16	4.0	110	.185	3.10
17	4.0	65	.150	3.0
18	1.5	48	.1168	3.0
19	3.0	48	.112	2.5
20	4.5	27	.092	2.5
21	4.5	20	.0767	2.5
22	19.0	20	.0767	2.5
23	19.5	950	.60	2.5
24	4.5	3500	.520	2.5
25	1.0	3500	.10	2.5
26	1.25	3	.10	2.5

Developed Data For Crash Pulse Simulator

Final coordinates: (at rebound)

$X = -2.37$ ft

$Y = 7.45$ ft

$\theta = 0.13$ rad

Final velocities and accelerations:

$\dot{X} = 78.59$ ft/sec

$\dot{Y} = -2.17$ ft/sec

$\dot{\theta} = -0.50$ rad/sec

Fuselage deflection	= 0.78 ft
Maximum ground deformation	= 0.45 ft
Length of groove formed between contact and rebound	= 20.8 ft

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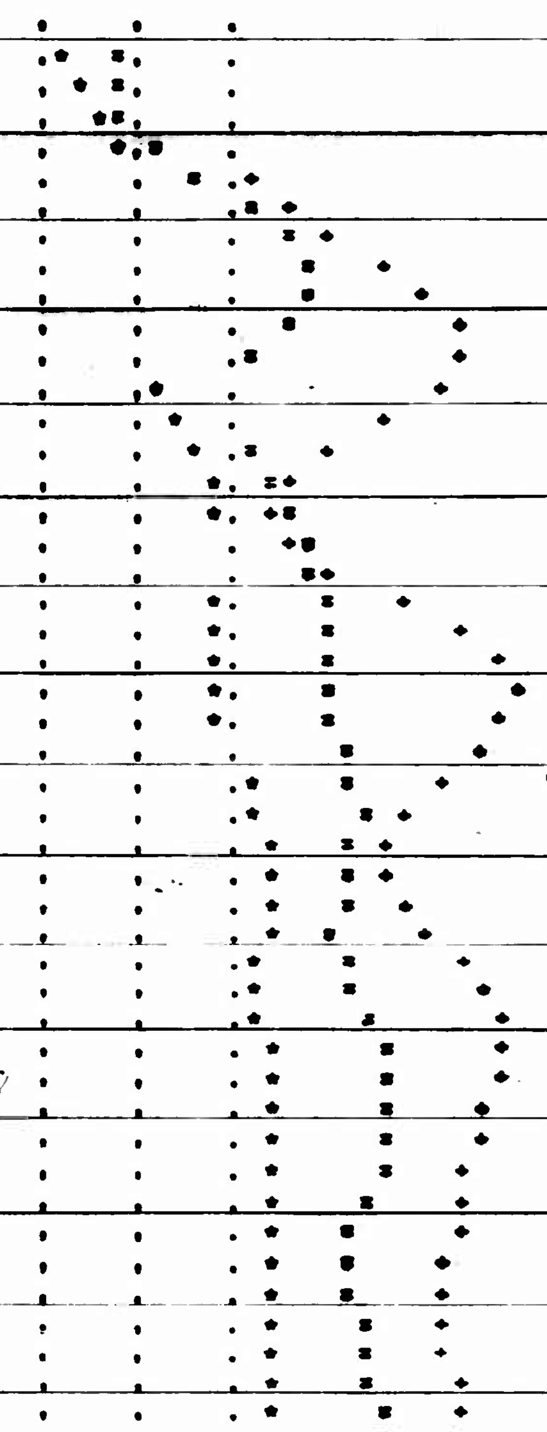
SIMULATOR PLOT OF ACCELERATION-TIME HISTORIES

DATE 9 8 66 RUN 2000

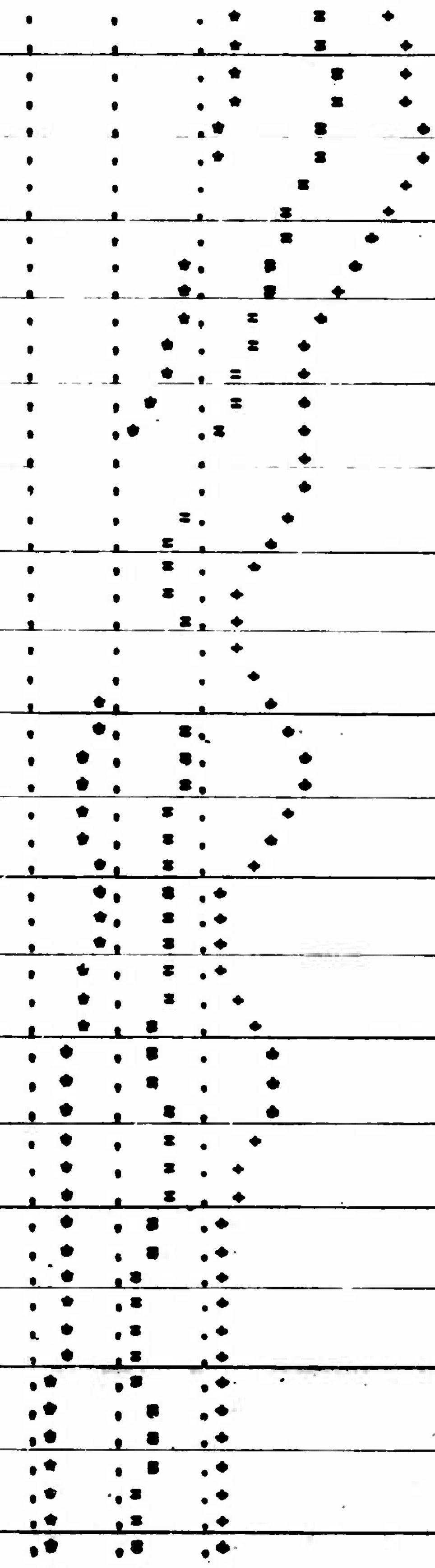
TIME	STA. A	STA. B	STA. C
0.000	0.00	0.00	0.00
0.002	0.73	-0.96	-0.11
0.004	1.57	-1.27	-0.18
0.006	2.54	-0.62	-0.15
0.008	3.60	0.94	0.18
0.010	4.67	3.03	1.04
0.012	5.15	5.90	2.65
0.014	5.38	8.02	4.93
0.016	5.36	8.94	7.56
0.018	5.20	8.66	9.99
0.020	5.11	7.58	11.56
0.022	5.28	6.30	11.79
0.024	5.81	5.41	10.56
0.026	6.68	5.22	8.21
0.028	7.73	5.78	5.50
0.030	8.72	6.83	3.32
0.032	9.43	7.98	2.44
0.034	9.73	8.91	3.21
0.036	9.63	9.43	5.49
0.038	9.27	9.58	8.64
0.040	8.87	9.55	11.78
0.042	8.65	9.56	14.09
0.044	8.75	9.78	15.02
0.046	9.20	10.24	14.48
0.048	9.89	10.81	12.84
0.050	10.66	11.29	10.75
0.052	11.32	11.51	8.91
0.054	11.74	11.41	7.88
0.056	11.88	11.06	7.87
0.058	11.80	10.66	8.78
0.060	11.61	10.43	10.24
0.062	11.43	10.54	11.78
0.064	11.36	11.02	13.01
0.066	11.42	11.77	13.70
0.068	11.61	12.57	13.82
0.070	11.84	13.17	13.53
0.072	12.05	13.39	13.03
0.074	12.18	13.19	12.52
0.076	12.23	12.66	12.10
0.078	12.22	11.99	11.81
0.080	12.19	11.43	11.60
0.082	12.17	11.14	11.44
0.084	12.17	11.19	11.31
0.086	12.18	11.52	11.25
0.088	12.16	11.98	11.31
0.090	12.06	12.43	11.52
0.092	11.85	12.68	11.88
0.094	11.53	12.63	12.28
[illegible]	[illegible]	[illegible]	[illegible]
0.086	12.18	11.52	11.2
0.088	12.16	11.98	11.3



45

A

0.088	12.16	11.98	11.3
0.090	12.06	12.43	11.52
0.092	11.85	12.68	11.88
0.094	11.53	12.63	12.28
0.096	11.14	12.26	12.56
0.098	10.73	11.65	12.57
0.100	10.34	10.93	12.17
0.102	10.01	10.23	11.36
0.104	9.72	9.64	10.22
0.106	9.45	9.16	8.94
0.108	9.13	8.76	7.74
0.110	8.72	8.37	6.83
0.112	8.19	7.93	6.30
0.114	7.55	7.39	6.14
0.116	6.84	6.77	6.19
0.118	6.10	6.11	6.28
0.120	5.40	5.47	6.18
0.122	4.84	4.77	5.77
0.124	4.71	3.68	4.98
0.126	4.72	3.87	3.94
0.128	4.81	3.04	2.86
0.130	4.92	3.47	2.02
0.132	4.95	4.10	1.68
0.134	4.83	4.66	1.98
0.136	4.54	4.93	2.88
0.138	4.13	4.85	4.10
0.140	3.70	4.47	5.26
0.142	3.34	3.96	5.97
0.144	3.15	3.50	5.99
0.146	3.15	3.21	5.26
0.148	3.30	3.11	4.00
0.150	3.50	3.13	2.57
0.152	3.66	3.18	1.35
0.154	3.69	3.16	0.68
0.156	3.56	3.01	0.67
0.158	3.29	2.77	1.24
0.160	2.94	2.52	2.14
0.162	2.60	2.34	3.05
0.164	2.35	2.31	3.68
0.166	2.22	2.40	3.86
0.168	2.20	2.56	3.57
0.170	2.25	2.69	2.96
0.172	2.31	2.69	2.21
0.174	2.32	2.51	1.54
0.176	2.27	2.17	1.09
0.178	2.16	1.76	0.89
0.180	2.00	1.38	0.92
0.182	1.83	1.14	1.06
0.184	1.68	1.08	1.24
0.186	1.57	1.19	1.37
0.188	1.48	1.39	1.43
0.190	1.41	1.59	1.43
0.192	1.34	1.69	1.40
0.194	1.24	1.63	1.34
0.196	1.13	1.42	1.27
0.198	1.02	1.11	1.16
0.200	0.93	0.88	0.97



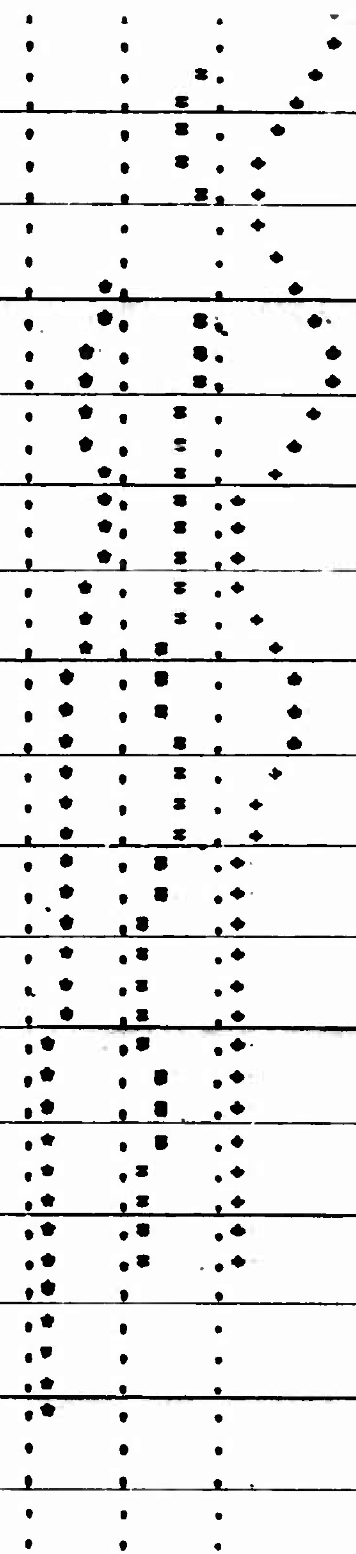
B

B

C

0.120	5.40	5.47	6.18
0.122	4.84	4.77	5.77
0.124	4.71	3.68	4.98
0.126	4.72	3.87	3.94
0.128	4.81	3.04	2.86
0.130	4.92	3.47	2.02
0.132	4.95	4.10	1.68
0.134	4.83	4.66	1.98
0.136	4.54	4.93	2.88
0.138	4.13	4.85	4.10
0.140	3.70	4.47	5.26
0.142	3.34	3.96	5.97
0.144	3.15	3.50	5.99
0.146	3.15	3.21	5.26
0.148	3.30	3.11	4.00
0.150	3.50	3.13	2.57
0.152	3.66	3.18	1.35
0.154	3.69	3.16	0.68
0.156	3.56	3.01	0.67
0.158	3.29	2.77	1.24
0.160	2.94	2.52	2.14
0.162	2.60	2.34	3.05
0.164	2.35	2.31	3.68
0.166	2.22	2.40	3.86
0.168	2.20	2.56	3.57
0.170	2.25	2.69	2.96
0.172	2.31	2.69	2.21
0.174	2.32	2.51	1.54
0.176	2.27	2.17	1.09
0.178	2.16	1.76	0.89
0.180	2.00	1.38	0.92
0.182	1.83	1.14	1.06
0.184	1.68	1.08	1.24
0.186	1.57	1.19	1.37
0.188	1.48	1.39	1.43
0.190	1.41	1.59	1.43
0.192	1.34	1.69	1.40
0.194	1.24	1.63	1.34
0.196	1.13	1.42	1.27
0.198	1.02	1.11	1.16
0.200	0.93	0.88	0.97
0.202	0.84	0.55	0.73
0.204	0.77	0.33	0.45
0.206	0.73	0.24	0.15
0.208	0.69	0.27	-0.10
0.210	0.64	0.36	-0.25
0.212	0.56	0.44	-0.25
0.214	0.44	0.46	-0.12
0.216	0.29	0.39	0.09
0.218	0.13	0.25	0.30
0.220	-0.02	0.07	0.41

REBOUND COMPLETE



APPENDIX V
CARGO SIMULATOR FORTRAN LISTING

```
      PROGRAM CRASH
      DIMENSION V(10),PV(10),A(9,4),H(9),WDD(30),Q(20),
     1PQ(20),PH1(32),PH2(32),PH3(32),PH4(32),CMU(32),ECA(32),ECB(32)
     1DF(32),CIM(32),AC(32),U(21),PU(21),OM(4),CM(4),SND(4),CSD(4),
     1CMOM(4),PLOT(71),PT(4),OMX(4),ZM(32)
   10 FORMAT(8F10.6)
      READ 10, VEL,SNK,THT,THTD
      READ 10, ((A(I,J),J=1,4),I=1,9)
      READ 10, CMA,CIA,SB,STRB,CDTH,RPM,CNS,DS,FMU,DT
      READ 10,CMU,CIM,DF,PH1,PH2,PH3,PH4,ECA,ECB,ZM
      READ 10,OM,CM,BETA
      READ 300,(PLOT(J),J=1,71),BLNK,PRD,AST,EQ,PLS
  300 FORMAT (71A1,5A1)
      READ 10,CLN,RLL,FLL
      READ 9,MNTH,NDAY,NYR,NRUN
    9 FORMAT (4I5)
      SMU=0.5
      SC=.75
   11 DO 12,J=1,10
   12 V(J)=0.
      RLL=RLL*32.2
      FLL=FLL*32.2
      LN=CLN
      V(3)=THT
      V(4)=SQRTF(VEL*VEL-SNK*SNK)
      V(5)=-SNK
      V(6)=THTD
      DO 14 I=1,2
   14 V(I) = A(I,1)+THT*(A(I,2)+THT*(A(I,3)+THT*A(I,4)))
      FN=9.
      IF (THT) 70,71,71
   70 V(1)=1./(1./A(1,1)-600.*THT)
   71 T1=SB-1./V(1)
      T2=V(2)*SINF(THT)-T1*COSF(THT)
      V(2)=V(2)*COSF(THT)+T1*SINF(THT)
      V(1)=T2
      FT=FN
      MXT=1
      NCR=1
      MRTN=1
      THTP = THT
      DO 17 I=3,9
   17 H(I) = A(I,1)+THT*(A(I,2)+THT*(A(I,3)+THT*A(I,4)))
      H3P=H(3)/(1.+4.*THT*THT)
      H4P=(1.+4.*THT*THT)/H(4)
      H5P = H(5)
      H6P=H(6)/(1.+8.*THT*THT)
      H7P=H(8)
      H8P=H(9)
      H1P=V(1)
```

```
      DO 13 J = 1,20
   13 Q(J)=0.
      T=0.
      NS=CNS
      OM(3) = OM(3) - BETA * BETA/4.0
      OM(4) = OM(4) - BETA * BETA/4.0
      DO 15 I = 1,4
      QMX(I)=0.
      CMOM(I)=SQRTF(OM(I))*CM(I)
      SND(I)=SINF(SQRTF(OM(I))*DT)
   15 CSD(I)=COSF(SQRTF(OM(I))*DT)
      SWCH= -1.0
      DO 301 J = 1,NS
  301 AC(J) = 0.
      DO 16 I = 3,4
      SND (I) = EXPF(-BETA/2. * DT) * SND(I)
   16 CSD(I) = EXPF(-BETA/2. * DT) * CSD(I)
      BT(1)=0.
      BT(2)=0.
      BT(3)=BETA
      BT(4)=BETA
      ZG = 0.
      FNC = 0.0
      FC=5.0
      FU = 2.0
      SH=40.
      ZDG = 0.
      ZGM = 0.
      STRM = 0.
      PRINT 200,MNTH,NDAY,NYR,NRUN
  200 FORMAT(1H1,20X,6H DATE ,3I4,20X,5H RUN ,I5//)
      PRINT 201
  201 FORMAT (5X,31H TIME    CARGO ACEL   FLOOR ACEL,3X,
     123H(*)  FLOOR,  (=)  CARGO)
      MSW = 1
      PVR = 0.
      VR = 0.
      PAR = 0.
      SR = 0.
      SRM = 0.
      SRL = 0.
      STRL=0.
      AR=0.
      MCR=1
      DO 112 I=1,3
  112 V(I)=V(3+I)*DT+V(I)
  110 PFN=FN
      DO 111 I=1,10
  111 PV(I)=V(I)
      THT=V(3)
```

```
      DO 113 I=1,9
  113 H(I)=A(I,1)+THT*(A(I,2)+THT*(A(I,3)+THT*A(I,4)))
      IF (THT) 117,118,118
  117 H(1)=SH
  118 T1=SB-1./H(1)
      H(4)=1./H(4)
      T2=H(2)*SINF(THT)-T1*COSF(THT)
      H(2)=H(2)*COSF(THT)+T1*SINF(THT)
      H(1)=T2
      V(10)=H(2)-V(2)
      ZD=(V(10)-PV(10))/DT
      Z=V(10)
  127 IF(T-.3) 180,700,700
  180 IF(V(4)) 114,114,181
  181 IF(Z) 114,114,182
  182 IF(V(3)-.8) 115,700,700
  114 PRINT 116
  116 FORMAT(18H REBOUND COMPLETE )
      GO TO 700
  115 SWCH = -1.0 * SWCH
      IF(ACLN) 570,571,571
  570 ACLN=0.
  571 IF(VR) 500,501,502
  501 IF (AC(LN)) 503,504,504
  504 IF (SRM - SR) 505,505,506
  505 IF (AC(LN) - RLL) 600,600,507
  507 AR = AC(LN) - RLL
  508 IF (VR) 517,518,519
  517 AR = AR + SMU * ACLN
      GO TO 520
  519 AR = AR - SMU * ACLN
      GO TO 520
  518 IF (ABSF(AR) - SMU * ACLN) 521,521,522
  521 AR = 0
      GO TO 514
  522 AR = AR * (1. - SMU * ACLN/ABSF(AR))
  520 VR = PVR + (AR + PAR) * DT/2.
      IF (VR * PVR) 509,510,510
  509 VR = 0.
      AR=0.
      GO TO 514
  510 SR = SR + (VR + PVR) * DT/2.
      IF (SR - SRM) 511,511,512
  512 SRM = SR
  511 IF (SR - SRL) 513,514,514
  513 SRL = SR
  514 PVR = VR
      PAR = AR
      GO TO 600
  506 AR = AC(LN)
```

```
      GO TO 508
  503 IF (SR - SRL) 515,515,506
  515 IF (- AC(LN) - FLL) 600,600,516
  516 AR = AC(LN) + FLL
      GO TO 508
  502 IF (SRM - SR) 507,507,506
  500 IF (SR - SRL) 516,516,506
  600 IF (SWCH) 318,530,531
  530 STOP
  531 GB =(AC(LN) - AR)/32.2
      K = GB + 26.5
      IF (K) 305,305,306
  306 IF (K-71) 307,307,305
  307 PLOT (K) = EQ
  305 GC = AC(LN)/32.2
      L = GC + 26.5
      IF (L) 308,308,309
  309 IF (L-71) 310,310,308
  310 PLOT (L) = AST
  308 PLOT (26) = PRD
      PRINT 311,T,GB,GC,PLOT
  311 FORMAT (5X,F5.3,2F12.2,71A1)
  312 IF (K) 315,315,316
  316 IF (K-71) 317,317,315
  317 PLOT (K) = BLNK
  315 IF (L) 318,318,319
  319 IF (L-71) 320,320,318
  320 PLOT (L) = BLNK
  318 GO TO(523,524),MCR
  523 DZ=ZD*DT
      COF=1.+4.*THT*THT
      H(3)=H(3)/COF
      H(4)=H(4)*COF
      H(6)=H(6)/(2.*COF-1.)
      IF(ZG - ZGM) 411,411,412
  412 ZGM=ZG
      ZSP=Z-ZG
  411 PZG = ZG
      IF (DZ) 119,120,120
  120 GO TO (800,801), MSW
  800 FUH=H(4)+ZDG * ZDG/H(5)
      CK=((1.0-SC)*H(8)*V(4)+1.0/H(3))/(2.0 * FUH)
      ZG=SQRTF(Z/(H(3)*FUH)+CK*CK)-CK
      ZS = Z - ZG
      FN = ZS/H(3)
      IF (FN-1./H(6)) 803,803,802
  802 MSW = 2
  801 FUH = H(4) + ZDG * ZDG /H(5)
      IF (FN - 1./H(6)) 804,805,805
  804 FCH = H(3)
```

```
      GO TO 806
  805 FCH = FC * H(3)
  806 DZG=DZ/((2.*FUH*ZG+(1.-SC)*H(8)*V(4))*FCH+1.0)
  899 ZG=ZG+DZG
      DZS = DZ - DZG
      DFN = DZS/FCH
      FN=PFN+DFN
      GO TO 803
  119 DZG=DZ*ZG/(Z-DZ)
      FCH = H(3)
      GO TO 899
  803 FNSC=(1.-SC)*H(8)*V(4)*ZG
      IF (FN-FNSC) 808,121,121
  808 FN=FNSC
  121 FT = FMU * FN + (H(8) * V(4) + H(9) * V(4) * V(4)) * ZG * SC
      ZDG = (ZG - PZG)/DT
      CTH=COSF(V(3))
      STH=SINF(V(3))
      P= FN*CTH-FT*STH
      C = FT * CTH + FN * STH
  123 GO TO (126,165),MRTN
  126 V(7)=-FT/CMA
      PNCR = NCR
      V(8)= FN/CMA
      V(9)=(FN*H(1)+FT*(V(2)+ZG/2.))/CIA
      DO 130 I=1,3
      V(3+I)=V(3+I)+(V(6+I)+PV(6+I))*DT/2.
  130 V(I)=V(I)+(V(3+I)+PV(3+I))*DT/2.
      SJ=DS/2.
      DO 131 J=1,NS
      WDD(J)=V(7)*STH+V(8)*CTH-V(9)*(SB-SJ)
  131 SJ=SJ+DS
      DO 132 I = 1,20
  132 PQ(I)=Q(I)
      SP=SB-(V(2)+ZG/2.)*STH+H(1)*CTH
      CMM=C*((V(2)+ZG/2.)*CTH+H(1)*STH)
      J=SP/DS+1.0
      Q(1) = P * PH1(J) + CMM * (PH1(J+1)-PH1(J))/DS
      Q(2) = P* PH2(J) + CMM * (PH2(J+1)-PH2(J))/DS
      Q(3)=C*PH3(J)
      Q(4)=C*PH4(J)
      ACEL = V(8) * STH - V(7) * CTH
      SJ = SB - DS/2.
      THSQ=V(6)*V(6)
      DO 133 J=1,NS
      Q(1) = Q(1)-CMU(J)*WDD(J)*PH1(J)
      Q(2) = Q(2)-CMU(J)*WDD(J)*PH2(J)
      Q(3) = Q(3) - CMU(J) * (ACEL + THSQ * SJ) * PH3(J)
      Q(4) = Q(4) - CMU(J) * (ACEL + THSQ * SJ) * PH4(J)
  133 SJ = SJ - DS
      DO 212 I = 1,4
```

```
      IF(T-DT/2.) 210,210,211
  210 Q(4 + I) = Q(I) * DT * DT/(6. * CM(I))
      Q(16 + I) = Q(4 + I) *3./(SQRTF(OM(I)) * DT)
      GO TO 213
  211 QT = PQ(16 + I) + PQ(I)/CMOM(I)*DT
      Q(4 + I) = PQ(4 + I) * CSD(I) + QT * SND(I)
      Q(16 + I) = QT * CSD(I) - PQ(4 + I) * SND(I)
  213 Q(12+I)=Q(I)/CM(I)-(OM(I)+BT(I)*BT(I)/4.)*Q(4+I)-BT(I)*PQ(8+I)
      IF(ABSF(Q(4+I))-QMX(I)) 212,212,214
  214 QMX(I)=ABSF(Q(4+I))
  212 Q(8 + I) = PQ(8 + I) + (Q(12 + I) + PQ(12 + I)) * DT/2.0
      PSTR=0.
      PPSTR=0.
      CMNT = CMA - CMU(1)/2.0
      SJ = SB - DS/2.
      PSHR=0.
      BMM=-CMM
      NPP=1
      DO 400 J = 1,NS
      AC(J)=ACFL+THSQ*SJ+Q(15)*PH3(J)+Q(16)*PH4(J)
      GO TO (143,144), MXT
  143 ACN=V(7)*STH+V(8)*CTH-V(9)*SJ
      IF (J - LN) 146,147,146
  147 ACLN = ACN+32.2*CTH
  146 SHR=PSHR+CMU(J)*ACN
      GO TO(401,402),NPP
  401 IF (SP-SB+SJ-DS/2.) 403,403,402
  403 NPP=2
      SHR=SHR-P
  402 BMM=BMM-(PSHR+SHR)*DS/2.+CIM(J)*V(9)
      PSHR=SHR
      STR=ECA(J)*Q(5)+ECB(J)*Q(6)
      STRN=(3.*STR+6.*PSTR-PPSTR)/8.
      IF(STRL-STRN) 191,191,190
  190 STRL=STRN
      JSTL=J
  191 IF(STRN-STRM) 413,414,414
  414 STRM = STRN
      JST=J
  413 IF(STRN - STRB) 140,141,141
  140 PPSTR=PSTR
      PSTR=STR
      GO TO 144
  141 JH=J-1
      SH = SB - SJ -DS/2.0
      PRINT 142,JH
  142 FORMAT(21H YIELD HINGE AT STA. ,I3)
      MXT=2
  144 CMNT = CMNT -(CMU(J) + CMU(J + 1))/2.0
  400 SJ = SJ - DS
  145 FORMAT (1X,10E11.4/)
```

```
      T=T+DT
      GO TO (110,149),MXT
  149 CMF=0.
      T=T-DT
      DO 150 N=1,JH
  150 CMF=CMF+CMU(N)
      CMR=CMA-CMF
      CLM=CMR/CMA
      TM=CMF/CMA
      RM=CMR/CMF
      SJ=DS/2.
      SBF=0.

      DO 152 N=1,JH
      SBF=SBF+CMU(N)*SJ
  152 SJ=SJ+DS
      SBF=SBF/CMF
      SBR=(CMA*SB-CMF*SBF)/CMR
      DSF=SB-SBF
      DSR=SBR-SB
      U(1)=V(1)+DSF*CTH
      U(2)=V(2)-DSF*STH
      U(3)=V(3)
      U(4)=V(1)-DSR*CTH
      U(5)=V(2)+DSR*STH
      U(6)=V(3)
      DO 151 I=1,3
      U(6+I)=V(3+I)
      U(9+I)=V(3+I)
      U(12+I)=V(6+I)
  151 U(15+I)=V(6+I)
      U(19)=V(1)+(SB-SH)*CTH-DF(JH)*STH
      U(20)=V(2)-(SB-SH)*STH-DF(JH)*CTH
      U(21)=V(10)
      RF=(SBF-SH)*(SBF-SH)+DF(JH)*DF(JH)
      RR=(SBR-SH)*(SBR-SH)+DF(JH)*DF(JH)
      SJ=DS/2.
      CIF=0.
      DO 153 N=1,JH
      CIF=CIF+CIM(N)+CMU(N)*SJ*SJ
  153 SJ=SJ+DS
      CIF=CIF-CMF*SBF*SBF
      CIR=CIA-CIF-CMF*(SB-SBF)*(SB-SBF)-CMR*(SB-SBR)*(SB-SBR)
      G1=(CIF/CMF+CLM*RF)/TM
      G5=(CIR/CMR+TM*RR)/TM
      DXF=U(1)-U(19)
      DYF=U(20)-U(2)
      MRTN=2
      DTH=0.
  160 PDTH = DTH
      PFN=FN
```

```
      DO 161 I=1,21
  161 PU(I)=U(I)
      DO 162 I=1,6
      U(6+I)=PU(6+I)+PU(12+I)*DT
  162 U(I) = PU(I) + (U(6+I) + PU(6+I))*DT/2.
      THT=U(3)
      DO 163 I=1,9
  163 H(I)=A(I,1)+THT*(A(I,2)+THT*(A(I,3)+THT*A(I,4)))
      STH=SINF(THT)
      CTH=COSF(THT)
      IF (THT) 157,158,158
  157 H(1)=SH
  158 T1=SB-1./H(1)
      H(4)=1./H(4)
      T2=H(2)*STH-T1*CTH
      H(2)=H(2)*CTH+T1*STH
      H(1)=T2
      STHR=SINF(U(6))
      CTHR=COSF(U(6))
      U(21)=H(2)-DSF*STH-U(2)
      Z=U(21)
      ZD=(U(21)-PU(21))/DT
      DO 164 I=1,2
      U(19)=PU(19)+(U(7)+PU(7)+(U(9)+PU(9))*DYF)*DT/2.
      U(20)=PU(20)+(U(8)+PU(8)+(U(9)+PU(9))*DXF)*DT/2.
      DXF=U(1)-U(19)
      DYF=U(20)-U(2)
      DXR=U(19)-U(4)
  164 DYR=U(5)-U(20)
      V(1) = U(1)
      V(2) = U(2)
      V(3)=U(3)
      V(4)=U(7)
      V(5). = U(8)
      V(6) = U(9)
      T=T+DT
      GO TO 127
  165 DTH=U(6)-U(3)
      IF(ABSF(DTH)-CDTH) 166,167,167
  167 PRINT 168
  168 FORMAT (15H FUSELAGE BREAK)
      GO TO 700
  166 PHM=STRB*ZM(JH)*(.5-11.1*DTH*DTH)
      IF(DTH-PDTH) 169,171,171
  169 PHM=-RPM*PHM
  171 G4=(DXF*DXR+DYF*DYR)
      G2=G4*RM
      F1=U(9)*U(9)
      F2=U(12)*U(12)
      F3=DXR*(F1*DYF+F2*DYR)-DYR*(F1*DXF+F2*DXR)
      G3=PHM/(CMF*TM)+FN*(U(19)/(CMF*TM)+DXF/CMF)+FT*((U(20)+.5*Z)/
```

```
      1(CMF*TM)-DYF/CMF)+RM*F3
       G6=-PHM/(CMR*TM)-FN*DXF/CMF+FT*DYR/CMF+F3
       DEN=G1*G5-G4*G2
       U(15)=(G3*G5-G2*G6)/DEN
       U(18)=(G1*G6-G3*G4)/DEN
       F4=F1*DXF+F2*DXR
       F5=F1*DYF+F2*DYR
       F6=DYF*U(15)
       F7=DYR*U(18)
       F8=DXF*U(15)
       F9=DXR*U(18)
       U(13)=-(FT+CMR*F4)/CMA-CLM*(F6+F7)
       U(16)=-(FT-CMF*F4)/CMA+TM*(F6+F7)
       U(14)=(FN+CMR*F5)/CMA-CLM*(F8+F9)
       U(17)=(FN-CMF*F5)/CMA+TM*(F8+F9)
       SJ=DS/2.
       DO 173 J=1,NS
       IF (J-JH) 174,174,175
  174  AC(J)=-U(13)*CTH+U(14)*STH+U(9)*U(9)*(SBF-SJ)
       GO TO 173
  175  AC(J)=-U(16)*CTHR+U(17)*STHR+U(12)*U(12)*(SBR-SJ)
  173  SJ=SJ+DS
       IF(CLN*3.-SH) 572,572,573
  572  ACLN=U(13)*STH+(U(14)+32.2)*CTH-U(15)*(SBF-CLN*3.)
       GO TO 160
  573  ACLN=U(16)*STH+(U(17)+32.2)*CTH-U(18)*(SBR-CLN*3.)
       GO TO 160
  700  AC(LN)=0.
       T=T+DT
       MCR=2
       ACLN=32.2
       GO TO 115
  524  T=T+DT
       IF(VR) 525,525,115
  525  PRINT 203,NRUN
  203  FORMAT(1H1,20X,15H INPUT DATA RUN,I5//)
       PRINT 204,VEL,SNK,THTP,FMU
  204  FORMAT(4H VEL,F7.2,6X,4H SNK,F6.2,
      16X,4H THT,F6.3,6X,11H FRICT COEF,F5.2/)
       PRINT 205,STRB,CDTH,BETA
  205  FORMAT(11H CR STRESS ,F10.3,6X,7H CR ANG,F6.3,6X,
      112H DAMP FACTOR,F7.3/)
       PRINT 206,H3P,H4P,H5P
  206  FORMAT(8H FN1=ZS/,E10.4,10X,11H FN2=ZG*ZG*,E10.4,10X,
      116H FN3=ZG*ZGD*ZGD/,E10.4/)
       PRINT 207,H6P,H7P,H8P
  207  FORMAT (7H FNC=1/,E10.4,10X,11H FT1=XD*ZG*,E10.4,10X,
      114H FT2=XD*XD*ZG*,E10.4//)
       PRINT 208
  208  FORMAT(20X,15H DEVELOPED DATA//)
       PRINT 209,(V(I),I=1,6)
  209  FORMAT(3H X ,F7.2,5X,3H Y ,F6.2,5X,6H THETA,F6.2,5X5H XDOT,F7.2,
```

```
     15X,5H YDOT,F7.2,5X,9H THETADOT,F6.2/)
      ZS=ZSP
      GL=V(1)-H1P
      PRINT 410,ZG,ZS,ZGM,GL,STRM
  410 FORMAT(12H GRND DEFORM,F5.2,5X,9H FUS DEFL,F5.2,5X,
     115H MAX GRND DEFRM,F6.2,5X,7H GROOVE,F7.2,5X,10H MAXSTRESS,E9.2/)
      PRINT 409,(QMX(I),I=1,4),JST
  409 FORMAT(29H GENERALIZED COORDINATES  Q1=,F10.5,3X,4H Q2=,F10.5,3X,
     14H Q3=,F10.5,3X,4H Q4=,F10.5,3X,12H MAX STR LOC,I5)
      STRL=ABSF(STRL)
      PRINT 192,STRL,JSTL
  192 FORMAT (10X,16H MAX TENS STRESS,E9.2,3X,16H LOCATION NUMBER,I5)
      PRINT 193
  193 FORMAT(1H0,5X,13HREAR LOAD LIM,5X,13H FWD LOAD LIM,4X,
     114H MAX FWD DISPL,4X,14H MAX AFT DISPL,4X,9H SECT LOC)
      PRINT 194,RLL,FLL,SRM,SRL,LN
  194 FORMAT(8X,F8.2,10X,F8.2,10X,F8.2,10X,F8.2,9X,I3///)
      PRINT 40
   40 FORMAT (1H1,11H INPUT DATA)
      PRINT 145,((A(I,J),J=1,4),I=1,9)
      PRINT 145, FC,SC
      PRINT 145, CMA,CIA,SP,STRB,CDTH,RPM,CNS,DS,FMU,DT
      NRUN=NRUN+1
      READ 10, VFL,SNK,THT,CLN,RLL,FLL
      IF(EOF,60) 999,11
  999 STOP
      END
```

INPUT DATA FOR CARGO SIMULATOR

Aircraft - CV-7 (Operational Light)

The input data is the same as that for the crash simulator, (refer to Appendix IV) plus the following:

CLN = 13.

RLL = 8.

FLL = 4.

Developed Data For Cargo Simulator

Same as for crash simulator, plus:

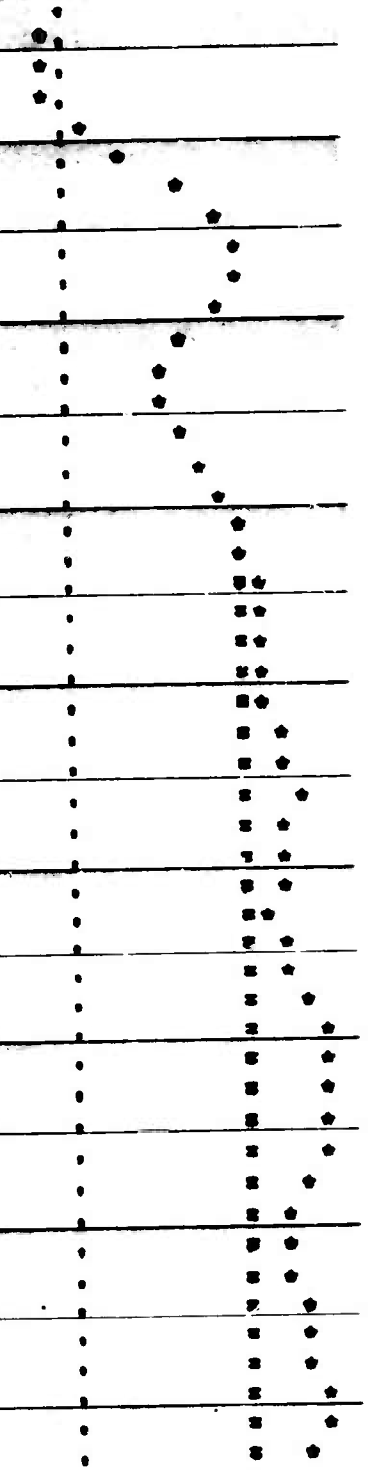
Maximum forward displacement of cargo relative to floor	=	0.33 ft

SIMULATOR PLOT OF CARGO AND FLOOR ACCELERATIONS

DATE 9 7 66 RUN 36

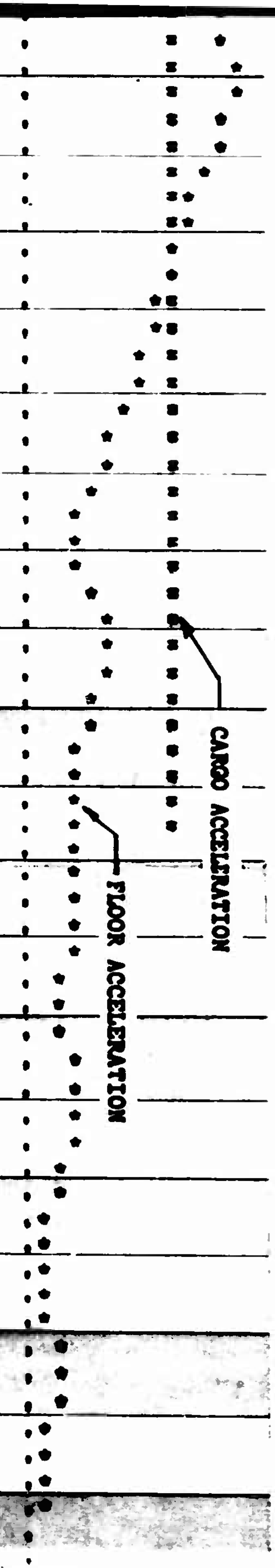
(*) FLOOR, (=) CARGO

TIME	CARGO ACEL	FLOOR ACEL
0.000	0.00	0.00
0.002	-0.96	-0.96
0.004	-1.27	-1.27
0.006	-0.62	-0.62
0.008	0.94	0.94
0.010	3.03	3.03
0.012	5.90	5.90
0.014	8.02	8.02
0.016	8.94	8.94
0.018	8.66	8.66
0.020	7.58	7.58
0.022	6.30	6.30
0.024	5.40	5.40
0.026	5.22	5.22
0.028	5.78	5.78
0.030	6.83	6.83
0.032	7.98	7.98
0.034	8.91	8.91
0.036	9.02	9.43
0.038	9.01	9.58
0.040	9.00	9.55
0.042	8.99	9.56
0.044	8.98	9.78
0.046	8.97	10.24
0.048	8.96	10.81
0.050	8.95	11.29
0.052	8.93	11.51
0.054	8.92	11.41
0.056	8.90	11.06
0.058	8.88	10.66
0.060	8.87	10.43
0.062	8.85	10.54
0.064	8.83	11.02
0.066	8.82	11.77
0.068	8.80	12.57
0.070	8.78	13.17
0.072	8.77	13.39
0.074	8.75	13.19
0.076	8.74	12.66
0.078	8.72	11.99
0.080	8.71	11.43
0.082	8.70	11.13
0.084	8.68	11.18
0.086	8.67	11.52
0.088	8.66	11.98
0.090	8.66	12.43
0.092	8.65	12.68
0.094	8.66	12.63
0.096	8.66	12.26



A

0.090	8.66	12.43
0.092	8.65	12.68
0.094	8.66	12.63
0.096	8.66	12.26
0.098	8.67	11.65
0.100	8.69	10.93
0.102	8.70	10.23
0.104	8.73	9.64
0.106	8.75	9.16
0.108	8.78	8.76
0.110	8.81	8.37
0.112	8.85	7.92
0.114	8.88	7.39
0.116	8.92	6.77
0.118	8.96	6.11
0.120	9.00	5.47
0.122	9.03	4.77
0.124	9.02	3.68
0.126	9.01	3.07
0.128	8.99	3.04
0.130	8.98	3.47
0.132	8.97	4.10
0.134	8.96	4.66
0.136	8.95	4.93
0.138	8.93	4.85
0.140	8.92	4.47
0.142	8.91	3.96
0.144	8.90	3.50
0.146	8.89	3.21
0.148	8.88	3.10
0.150	8.87	3.13
0.152	3.18	3.18
0.154	3.16	3.16
0.156	3.01	3.01
0.158	2.77	2.77
0.160	2.52	2.52
0.162	2.34	2.34
0.164	2.30	2.30
0.166	2.40	2.40
0.168	2.56	2.56
0.170	2.69	2.69
0.172	2.69	2.69
0.174	2.51	2.51
0.176	2.17	2.17
0.178	1.76	1.76
0.180	1.38	1.38
0.182	1.14	1.14
0.184	1.08	1.08
0.186	1.19	1.19
0.188	1.39	1.39
0.190	1.59	1.59
0.192	1.69	1.69
0.194	1.63	1.63
0.196	1.42	1.42
0.198	1.10	1.10
0.200	0.88	0.88
0.202	[illegible]	[illegible]
0.204	0.33	0.33
[illegible]	0.24	0.24



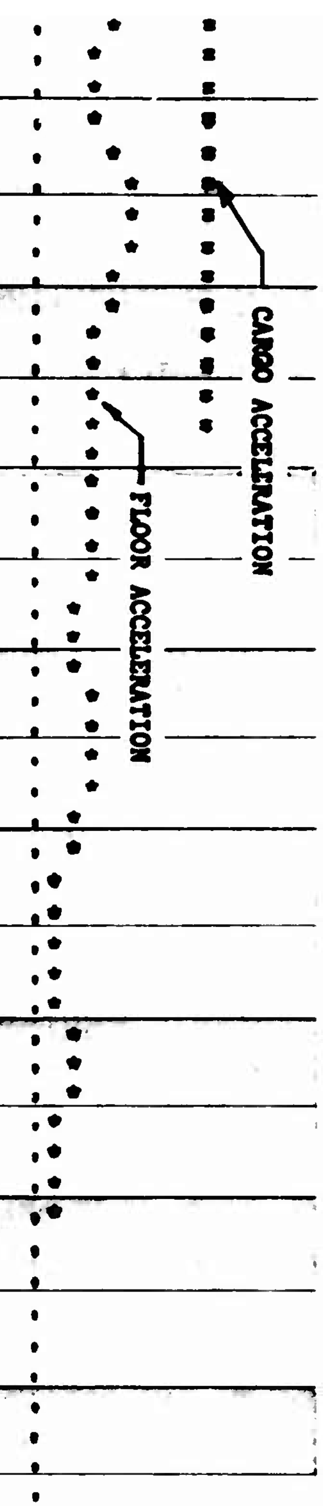
B

B

C

0.124	9.02	3.68
0.126	9.01	3.07
0.128	8.99	3.04
0.130	8.98	3.47
0.132	8.97	4.10
0.134	8.96	4.46
0.136	8.95	4.93
0.138	8.93	4.85
0.140	8.92	4.47
0.142	8.91	3.96
0.144	8.90	3.50
0.146	8.89	3.21
0.148	8.88	3.10
0.150	8.87	3.13
0.152	3.18	3.18
0.154	3.16	3.16
0.156	3.01	3.01
0.158	2.77	2.77
0.160	2.52	2.52
0.162	2.34	2.34
0.164	2.30	2.30
0.166	2.40	2.40
0.168	2.56	2.56
0.170	2.69	2.69
0.172	2.69	2.69
0.174	2.51	2.51
0.176	2.17	2.17
0.178	1.76	1.76
0.180	1.38	1.38
0.182	1.14	1.14
0.184	1.08	1.08
0.186	1.19	1.19
0.188	1.39	1.39
0.190	1.59	1.59
0.192	1.69	1.69
0.194	1.63	1.63
0.196	1.42	1.42
0.198	1.10	1.10
0.200	0.88	0.88
0.202	0.55	0.55
0.204	0.33	0.33
0.206	0.24	0.24
0.208	0.27	0.27
0.210	0.36	0.36
0.212	0.44	0.44
0.214	0.46	0.46
0.216	0.39	0.39
0.218	0.25	0.25
0.220	0.07	0.07

REBOUND COMPLETE



APPENDIX VI
PROGRAM VIBRAT FORTRAN LISTING

```
      PROGRAM VIBRAT
      DIMENSION PH(32),EI(32),EC(32),PHA(32),PLOT(71),CMU(32),V(32),
     1 BM(32), CF(32),AS(32)
    8 FORMAT(8F10.4)
    6 READ 9,DS,EPS,NS,MSW
    9 FORMAT(2F10.4,2I10)
      READ 8, AS,EI,EC,CMU
      READ 7,(PLOT(J),J=1,71),BLNK,STAR,PRD
    7 FORMAT (71A1,3A1)
      E= 1500000000.0
      CNS=NS
      COF = 6.24 / (CNS*DS)
      SJ=DS/2.
      DO 899 J=1,NS
      PH(J)= COSF(COF*SJ)
  899 SJ=SJ + DS
      ROM = 0.
      SJ = DS/2.
      F1 = CMU(1) * SJ/4.
      F2 = (5. * CMU(1) - CMU(2))/8.
      F3 = F1 * DS/4.
      F4 = F2 * DS/4
      DO 900 J = 2,NS
      DF1 = CMU(J - 1) * SJ
      SJ = SJ + DS
      DF1 = (DF1 + CMU(J) * SJ) /2.
      F1 = F1 + DF1
      F3 = F3 + (F1 - DF1/2.) * DS
      DF2 = (CMU(J - 1) + CMU(J))/2.
      F2 = F2 + DF2
  900 F4 = F4 + (F2 - DF2/2.) * DS
      DF1 = (CMU(NS) * (SJ + DS/4.))/2.
      F1 = F1 + DF1
      F3 = F3 + (F1 - DF1/2.) * DS/2.
      DF2 = CMU(NS)/2.
      F2 = F2 + DF2
      F4 = F4 + (F2 - DF2/2.) * DS/2.
      MXT = 1
  901 V(1)=(5.*CMU(1)*PH(1)-CMU(2)*PH(2))/8.
      BM(1) = V(1) * DS/4.
      DO 902 J = 2,NS
      DV=(CMU(J-1)*PH(J-1)+CMU(J)*PH(J))/2.
      V(J) = V(J - 1) + DV
  902 BM(J) = BM(J - 1) + (V(J) - DV/2.) * DS
      GO TO (903,904),MXT
  903 DV=(5.*CMU(NS)*PH(NS)-CMU(NS-1)*PH(NS-1))/8.
      VF = V(NS) + DV
      BMF = BM(NS) + (V(NS) + DV/2.) * DS/2.
      DEN = F1 * F4 - F2 * F3
      C1 = (F2 * BMF - F4 * VF)/DEN
```

```
      C2 = (E3 * VE - [illegible] * BME)/DEN
      SJ = DS/2.
      OM = 1./(PH(1) + C1 * SJ + C2)
      DO 905 J = 1,NS
      PH(J) = PH(J) + C1 * SJ + C2
  905 SJ = SJ + DS
      MXT = 2
      GO TO (918,919),MSW
  911 PHP = (BM(1)/EI(1)) * DS/4.
      PH(1) = PHP * DS/4.
      DO 907 J = 2,NS
      DPHP = (BM(J - 1)/EI(J - 1) + BM(J)/EI(J)) * DS/2.
      PHP = PHP + DPHP
  907 PH(J) = PH(J - 1) + (PHP - DPHP/2.) * DS
      PRINT 99,PH
      GO TO 901
  904 DOM=ABSF(OM-POM)
      POM = OM
      MXT = 1
      IF (DOM - EPS) 908,908,911
  908 DO 909 J = 1,NS
      PLOT(36)=PRD
      IF(ABSF(PH(J))-1.7) 502,502,503
  502 PHI=35.+PH(J)*20.
      N = PHI + 1.5
      PLOT(N) = STAR
  503 PRINT 10,J,PH(J),PLOT
   10 FORMAT (I3,4X,F8.4,10X,71A1//)
  909 PLOT(N) = BLNK
      PRINT 11, OM
   11 FORMAT(1H1,10X,F12.3///)
      DO 910 J = 1,NS
      ECPH = BM(J) * EC(J)/EI(J) * OM
  910 PRINT 12,ECPH,J
   12 FORMAT (20X,F10.3,I3)
      GO TO (921,922),MSW
  921 MSW = 2
      POM=0.
      EPS=1.0
      CM1 = 0.
      DO 914 J = 1,NS
      CM1 = CM1 + CMU(J) * PH(J) * PH(J)
  914 PHA(J) = PH(J)
      PRINT 14, CM1
      PRINT 13
   13 FORMAT(1H1,12H SECOND MODE)
      SJ=DS/2.
      COF=9.42 / (CNS*DS)
      DO 915 J=1,NS
```

```
      PH(J)=COSF(COF*SJ)
  915 SJ=SJ+DS
  919 CM = 0.
      DO 916 J = 1,NS
  916 CM = CM + CMU(J) * PH(J) * PHA(J)
      A = CM/CM1
      DO 917 J = 1,NS
  917 PH(J) = PH(J) - A * PHA(J)
      GO TO (901,918),MXT
  918 FACT=1./PH(1)
      DO 920 J=1,NS
  920 PH(J)=PH(J)*FACT
   99 FORMAT (5X,10F11.4)
      GO TO 901
  922 CM=0.
      EPS=.0001
      DO 950 J=1,NS
  950 CM=CM + CMU(J)*PH(J)*PH(J)
      PRINT 14, CM
      MSW=1
      COF=COF/3.
  947 SJ=DS/2.
      POM=0.
      DO 930 J=1,NS
      PH(J)=COSF(COF*SJ)
  930 SJ=SJ + DS
      PRINT 99,PH
  931 CNUM= (5.*CMU(1)*PH(1)-CMU(2)*PH(2))/8.
      DO 932 J=2,NS
      DCNUM=(CMU(J-1)*PH(J-1) + CMU(J)*PH(J))/2.
  932 CNUM=CNUM + DCNUM
      DCNUM= (5.*CMU(NS)*PH(NS)-CMU(NS-1)*PH(NS-1))/8.
      C1=(CNUM + DCNUM)/F2
      OM=1. / (PH(1)-C1)
      GO TO (937,938), MSW
  937 DO 933 J=1,NS
  933 PH(J)=(PH(J)-C1)*OM
  949 DOM=OM-POM
      PRINT 99,CNUM,C1,OM,A,CM,CM1
      POM=OM
      PRINT 99,PH
      IF(ABSF(DOM/OM)-EPS) 934,934,935
  935 CF(1)= (5.*CMU(1)*PH(1) - CMU(2)*PH(2))/8.
      DO 936 J=2,NS
      DCF= (CMU(J-1)*PH(J-1) + CMU(J)*PH(J))/2.
  936 CF(J)= CF(J-1) + DCF
      PRINT 99,CF
      PH(1)= CF(1)*DS / (4.*F*AS(1))
      DO 939 J=2,NS
      DPH= (CF(J-1) / AS(J-1) + CF(J) / AS(J)) *DS / (2.*F)
```

```
939 PH(J)= PH(J-1) + DPH
    PRINT 99,PH
    GO TO 930
938 CM=0.
    DO 940 J=1,NS
    PH(J)=PH(J)-C1
940 CM=CM + CMU(J)*PH(J)*PHA(J)
    A=CM / CM1
    OM=1./(PH(1)-A*PHA(1))
    DO 941 J=1,NS
941 PH(J)=(PH(J)-A*PHA(J))*OM
    GO TO 949
934 DO 942 J=1,NS
    IF(ABSF(PH(J))-1.7) 500,500,501
500 PHI=35.+PH(J)*20.
    N=PHI + 1.5
    PLOT(N)=STAR
    PLOT(36)=PRD
501 PRINT 10,J,PH(J),PLOT
942 PLOT(N)=BLNK
    OM=ABSF(OM)
    PRINT 11,OM
    DO 943 J=1,NS
    SG=CF(J) * OM / AS(J)
943 PRINT 12,SG,J
    GO TO (944,945), MSW
944 MSW=2
    CM1=0.
    DO 946 J=1,NS
    CM1=CM1 + CMU(J)*PH(J)*PH(J)
946 PHA(J)=PH(J)
    COF=COF * 2.
    PRINT 14,CM1
    PRINT 13
    GO TO 947
 14 FORMAT (18H GENERALIZED MASS ,F12.2)
945 CM=0.
    DO 948 J=1,NS
948 CM=CM + CMU(J)*PH(J)*PH(J)
    PRINT 14,CM
    GO TO 6
    END
```

INPUT FOR PROGRAM VIBRAT

DS = 3.0

EPS = 0.10

NS = 26.

MSW = 1

CMU = refer to Appendix IV

	AS	EI	EC
1	.05	.7E8	4.33E9
2	.037	1.455E8	5.76E9
3	.037	3.0E8	5.76E9
4	.033	4.89E8	7.74E9
5	.1190	15.20E8	9.48E8
6	.1122	17.5E8	9.17E9
7	.1165	17.6E8	9.28E9
8	.1118	15.8E8	8.80E9
9	.1360	29.3E8	9.97E9
10	.1360	29.3E8	11.25E9
11	.1124	24.2E8	9.80E9
12	.1228	27.4E8	11.52E9
13	.1110	23.0E8	8.8E9
14	.0971	15.8E8	8.8E9
15	.0784	8.85E8	4.8E9
16	.0735	8.48E8	4.4E9
17	.0686	6.64E8	4.32E9
18	.0660	5.15E8	4.36E9
19	.0610	4.13E8	3.60E9
20	.0680	3.21E8	3.60E9
21	.0631	2.82E8	3.60E9
22	.20	2.82E8	3.60E9
23	.20	22.1E8	3.60E9
24	.20	19.2E8	3.60E9
25	.20	1.77E8	3.60E9
26	.20	1.49E8	3.60E9

OUTPUT OF PROGRAM VIBRAT

OM(1) = 3573.09

OM(2) = 21774.42

OM(3) = 59345.91

OM(4) = 106076.68

	PH1	PH2	PH3	PH4
1	1.0	1.0	1.0	1.0
2	.8192	.6066	.9664	.9403
3	.6456	.2713	.8666	.7681
4	.4840	.0249	.7209	.5252
5	.3359	-.1321	.6059	.3405
6	.1991	-.2223	.5215	.2123
7	.0737	-.2535	.4270	.0763
8	-.0366	-.2156	.3081	-.0575
9	-.1299	-.1114	.1587	-.1596
10	-.2082	.0367	-.0063	-.2027
11	-.2724	.2081	-.1952	-.1961
12	-.3214	.3904	-.3897	-.1674
13	-.3550	.5713	-.5770	-.1322
14	-.3715	.7379	-.7762	-.0876
15	-.3647	.8723	-1.0014	-.0313
16	-.3273	.9547	-1.2483	.0338
17	-.2567	.9728	-1.5021	.1031
18	-.1510	.9177	-1.7613	.1753
19	-.0079	.7820	-2.0282	.2505
20	.1735	.5664	-2.2802	.3221
21	.3909	.2848	-2.5099	.3879
22	.6374	-.0311	-2.6511	.4285
23	.9011	-.3493	-2.6904	.4399
24	1.1703	-.6589	-2.7065	.4445
25	1.4424	-.9253	-2.7116	.4460
26	1.7212	-1.0710	-2.7136	.4465

ECA(J), ECB(J):

	ECA	ECB
1	5.165E5	3.806E6
2	4.[illegible]7E6	2.760E7
3	7.910E6	4.016E7
4	1.406E7	6.318E7
5	9.295E6	3.747E7
6	1.132E7	4.142E7
7	1.511E7	5.038E7
8	1.979E7	5.679E7
9	1.390E7	2.996E7
10	1.715E7	2.424E7
11	1.805E7	1.454E7
12	1.802E7	5.221E6
13	1.618E7	-2.359E6
14	2.082E7	-9.837E6
15	1.834E7	-1.292E7
16	1.576E7	-1.361E7
17	1.687E7	-1.620E7
18	1.830E7	-1.830E7
19	1.538E7	-1.504E7
20	1.513E7	-1.266E7
21	1.203E7	-4.982E6
22	7.407E6	5.394E6
23	5.370E5	1.852E6
24	3.941E5	2.989E6
25	3.356E6	3.741E7
26	3.563E6	4.793E7

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13. ABSTRACT

This report presents the findings of an investigation into the crash pulse of fixed-wing cargo aircraft and the resulting behavior of cargo restrained by load limiters.

A crash pulse simulator computer program was developed that obtains acceleration-time histories at selected stations in the cargo compartment and under various crash conditions. This simulator was employed to obtain crash pulses for a wide range of input parameters, both for the CV-2 and the CV-7 Army aircraft. The resulting acceleration pulses were studied to determine a suitable spectrum of realistic pulses.

The crash pulse program was subsequently modified to include a routine that would simulate cargo dynamic behavior during the crash sequence, employing the floor acceleration data as it is developed. This latter program was applied to CV-2 and CV-7 aircraft, under significant crash conditions, to obtain the dynamic response of cargo to the crash pulse.

DD FORM 1 JAN 64 1473

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14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
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